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SCOPING STUDY ON EROSION AND SEDIMENTATION IN THE DRINA RIVER BASIN

FINAL REPORT

JAROSLAV ČERNI WATER INSTITUTE

Belgrade, November 2019

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Belgrade, November 2019

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CONTENT:

1. PREFACE

The Scoping study on erosion and sedimentation in the Drina River Basin was prepared in the Jaroslav Cerni Water Institute (JCWI) for UNECE Drina Nexus Follow-Up Project, supported by the Italian Ministry for the Environment, land and the Sea.

This scoping study intends to provide a consistent picture about the occurrence of sedimentation and erosion in the basin and related existing problems, using data available in the three basin-sharing countries (Montenegro, Bosnia and Herzegovina and Serbia).

The Study is based on a combination geological/earth scientific and engineering expertise with water management and hydraulic infrastructure expertise. Also, the knowledge of the regional and the Sava River Basin level institutional and policy framework gave the direction to the management actions and follow-up of this Study.

The study datasets and geographical information system (GIS) shapefiles are also developed as part of the services and will be shared with the authorities and institutions concerned by erosion and sedimentation in the riparian countries.

Preparation of the Study included the following steps:

- Collection of data from national authorities;
- Situation analysis;
- Identification of sources of sediment in the Drina River basin;
- Identification of areas with a deficit/surplus of sediment in the Drina River Basin;
- Analysis of the anthropogenic impact on erosion/deposition
- Identification of possible measures
- Proposal of priority measures.

2. COLLECTION AND REVIEW OF DATA AND DOCUMENTATION

As a first step, JCWI prepared a questionnaire which was delivered to competent authorities in Serbia, Bosnia and Herzegovina (Federation of Bosnia and Herzegovina and Republika Srpska) and Montenegro in order to assess the status and availability of documentation and data related to erosion.

The result was as follows:

Montenegro: only data from Water Management Master Plan from 1997 are available. Data and shapefiles are used for this Study, with permission of Water administration. The erosion map for the Drina River basin in Montenegro was prepared according to the method of "Erosion Potential", in which erosion was classified into 5 qualitative-quantitative categories, corresponding to the average value of the erosion coefficient - Z.

Bosnia and Herzegovina, Federation of Bosnia and Herzegovina: Competent authorities form FB&H didn't respond to questionnaire; therefore, data are not available for this Study.

Bosnia and Herzegovina, Republic of Srpska: erosion data were obtained from PE "Water of Srpska" in pdf format, without accompanying text. The erosion map for this DRB part was prepared according to the modified method of Gavrilovic, which contains 5 erosion categories divided into subcategories. The .pdf file was digitalised to obtain shape files for GIS map of the entire DRB basin.

Serbia: only data from Water Management Master Plan from 2001 are available. Data and shapefiles are used for this Study, with permission of Ministry of agriculture, forestry and water management, Directorate for Water. An erosion map was prepared according to the method of "Erosion Potential", in which erosion was classified into 5 qualitative-quantitative categories, corresponding to the average value of the erosion coefficient - Z.

Other sources of information used for this Study are:

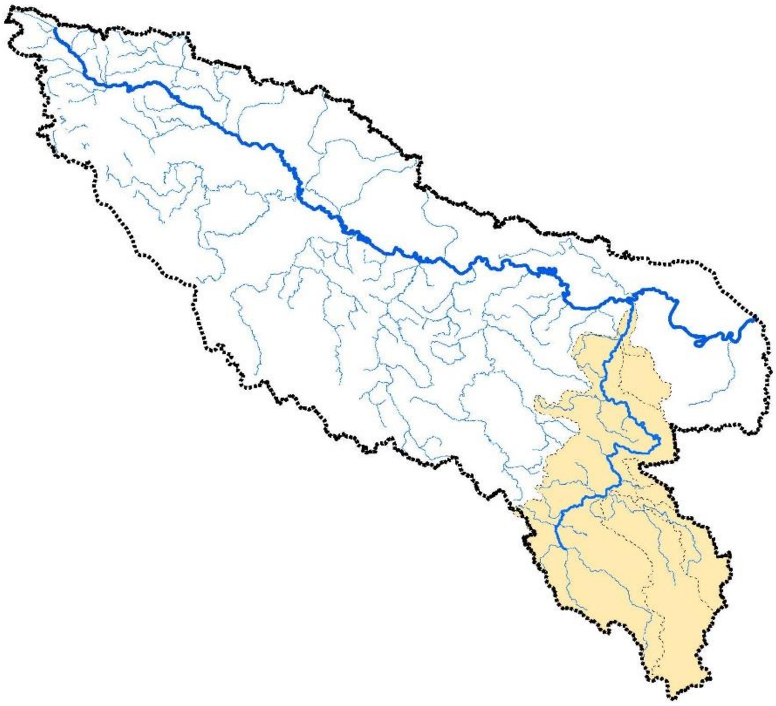
- Water management strategy for the territory of the Republic of Serbia by 2034
- Water Development Master Plan of the Republic of Serbia, 2001
- Water Development Master Plan of the Republic of Montenegro, 2001
- Water management strategy for the territory of the Montenegro
- General project of erosion and torrential areas in Serbia 2003-2009
- Water management strategy of Federation Bosnia and Herzegovina 2010-2022.
- Integrated water management strategy of Republic of Srpska till 2024.
- Support to water resources management in the Drina River Basin, Cowi, Stucky and Jaroslav Cerni Water Institute, 2017.
- Towards Practical Guidance for Sustainable Sediment Management using the Sava River Basin as a Showcase - Estimation of Sediment Balance for the Sava River, ISRBC, 2013

- Sava river basin management plan, ISRBC, 2014
- Different studies and designs prepared by JCWI.

3. CHARACTERISTICS OF THE DRINA RIVER BASIN

The Drina River is the largest tributary of the Sava River Basin, which in turn is the largest tributary by volume of water of the Danube River Basin that drains into the Black Sea.

The Drina River Basin (DRB) has a surface area of 19,680 km^2 and spreads over the territory of three main riparian states: Bosnia and Herzegovina (BiH), which is subdivided into two entities, Republic of Srpska (RS) and Federation of Bosnia-Herzegovina (FBiH), Montenegro (MNE), and Republic of Serbia (RS). In addition, Albania accounts for a very small part of the DRB (<1%).



Drina River Basin as a part of the Sava River Basin

The Drina River originates in Montenegro at an altitude of 2,500 m a.s.l. between the slopes of the Maglić and Pivska Planina mountains, between the villages of Šćepan Polje (in Montenegro) and Hum (in Bosnia and Herzegovina), draining a substantial karst plateau that receives the highest annual rainfall in Europe (about 3,000 mm/a), resulting also in the highest specific runoff in Europe (up to 50 $l/s/km^2$).

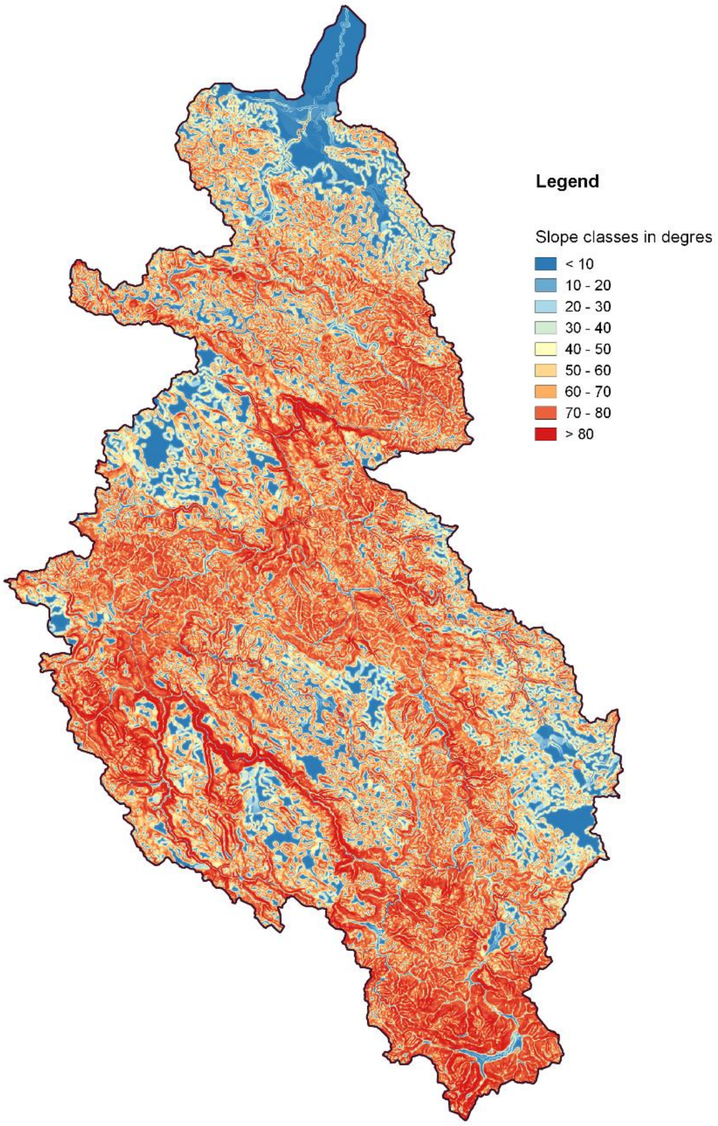
Basic characteristics of DRB that influence the sediment balance, as its relief, river network, land cover, climate, and runoff are given below.

3.1 Relief

Terrain in DRB significantly changes from the upper part towards its confluence with the Sava River in the north. The southern part is hilly and mountainous, particularly in Montenegro and Northern Albania. The northern part are plains of Semberia and Macva.

The average altitude of the DRB is 961.6 m a.s.l., but it ranges from 75.4 m a.s.l. at the mouth to more than 2,500 m a.s.l. on the highest mountains (e.g. Prokletije Mountain 2,694 m a.s.l., Komovi Mountain 2,487 m a.s.l. and Durmitor Mountain 2,522 m a.s.l.).

One of the main factors influencing the sediment yield and transport is slope gradient of the terrain in DRB. The slope gradient was estimated using DTM based on SRTM.

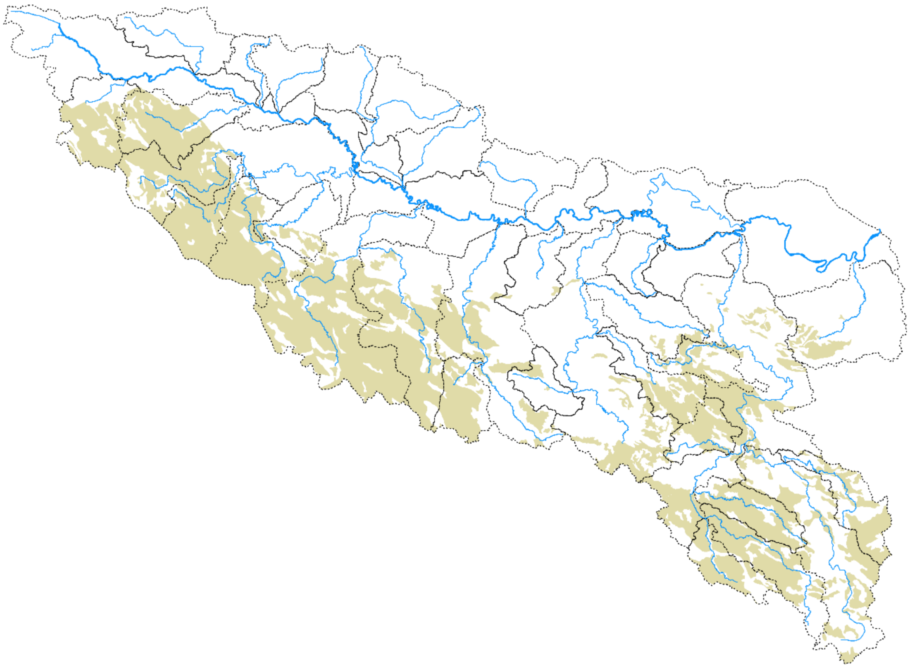


Slope gradient in DRB

3.2 Geology

The very important geological characteristic of DRB, influencing the regime of water and sediment is the presence of the karst phenomena. According to results of DIKTAS project (diktas.iwlearn.org), Dinaric karst region spreads from the Italian to the Albanian frontier, covering also a part of the Drina River Basin. Karst regions are present only in the southern part of the river basin. This terrain mostly belongs to the zone of the External Dinarides. It mostly consists from very thick layers of limestones of the Jurassic and the Cretaceous age (shaded part of the Figure below).

The rest of the river basin, between the External Dinarides and the border of the Sava catchment belongs to the Inner Dinarides zone and Pannonian basin. In this zone, limestones are much rarely in comparison with the zone of the External Dinarides, with prevailing of following lithological units: sandstone, marls, claystones, intrusive and extrusive igneous rocks (diabase, spilite, dacite, andesite etc), metamorphic rocks (serpentinite, phylite, argiloshist etc). The main aquifers are formed in alluvial deposits. The aquifers characterise large reserves of groundwater, especially alluvial deposits.



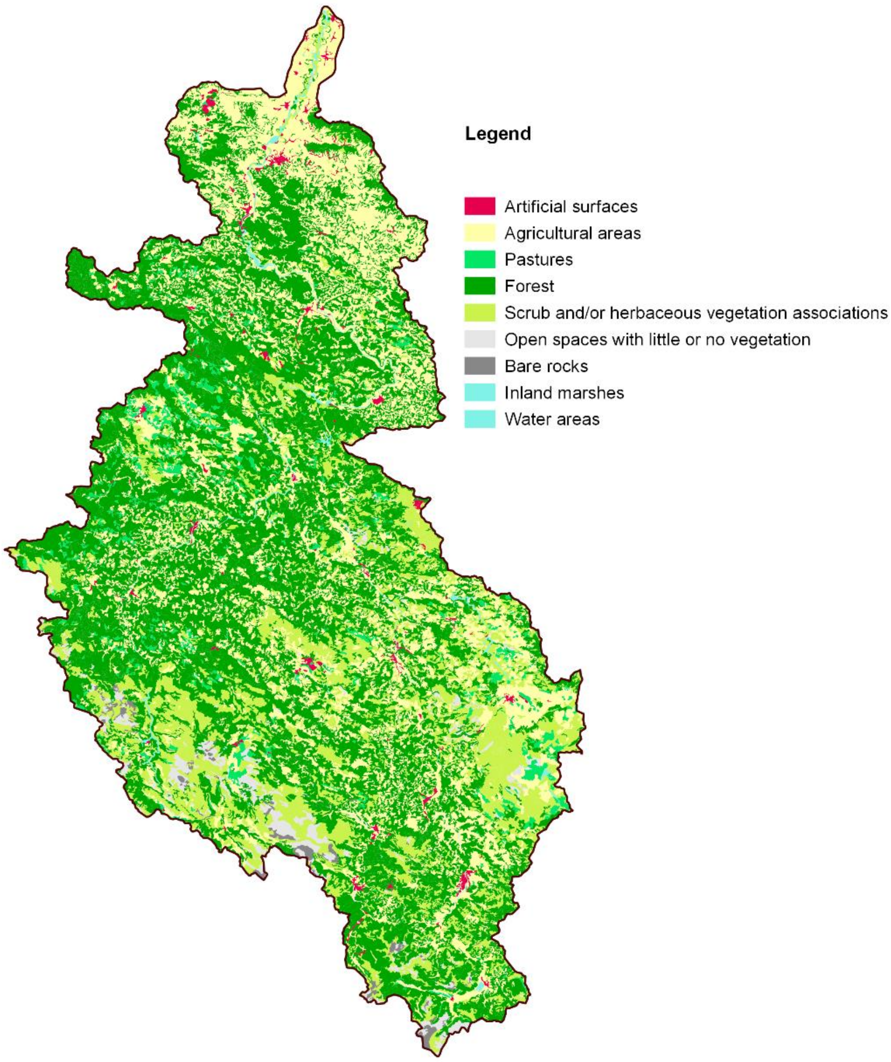
Dinaric karst regions in the Sava River Basin

3.3 Land cover

Forests (broad-leaved forest, coniferous forest and mixed forest) cover 50.61% of the total DRB area. The second largest category is agricultural land (non-irrigated arable land, fruit trees and berry plantations, complex cultivation patterns and land principally occupied by agriculture, with significant areas of natural vegetation), covering 24.14%. Scrub and/or herbaceous vegetation associations cover 17,46% of the DRB. The following are pastures with a 3.38% share. Open spaces with little or no vegetation, bare rocks and water areas are present at 3,48% of the total area.

CORINE percentages of land cover in the Drina river basin

CORINE type of land cover	Participation (%)
Artificial surfaces	0.93
Agricultural areas	24.14
Pastures	3.38
Forests	50.61
Scrub and/or herbaceous vegetation associations	17.46
Open spaces with little or no vegetation	2.25
Bare rocks	0.57
Water areas	0.67
∑	100.00



Land cover in DRB

3.4 Climate

Climate of the DRB is complex and influenced by general atmospheric circulation, its elongate shape in north-south direction, local orography and proximity of the Adriatic Sea. The southernmost part of the basin has a Mediterranean and a maritime temperate and humid climate according to the Köppen climate classification. Moderately cold and humid continental climate can be found at the altitudes above 1,000 m.

Mediterranean influence, although mild, can be found in the upper part of the basin, up to Foča. From that point downstream a temperate continental climate prevails with warm summers and moderately cold winters.

Generally, from south to north, along the altitude decline, accumulated annual precipitation also decreases, from about 2,100 mm measured in Kolašin on average to 820 mm in Loznica. In the same direction, mean annual temperature increases from 4.6 °C in Žabljak to 11 °C in Loznica. Seasonal distribution of precipitation differs throughout the DRB. Northern parts receive the most rain in the late spring, mainly in May and June, while winter is dry with the lowest precipitation in February. Due to the influence of the Mediterranean climate in the southern

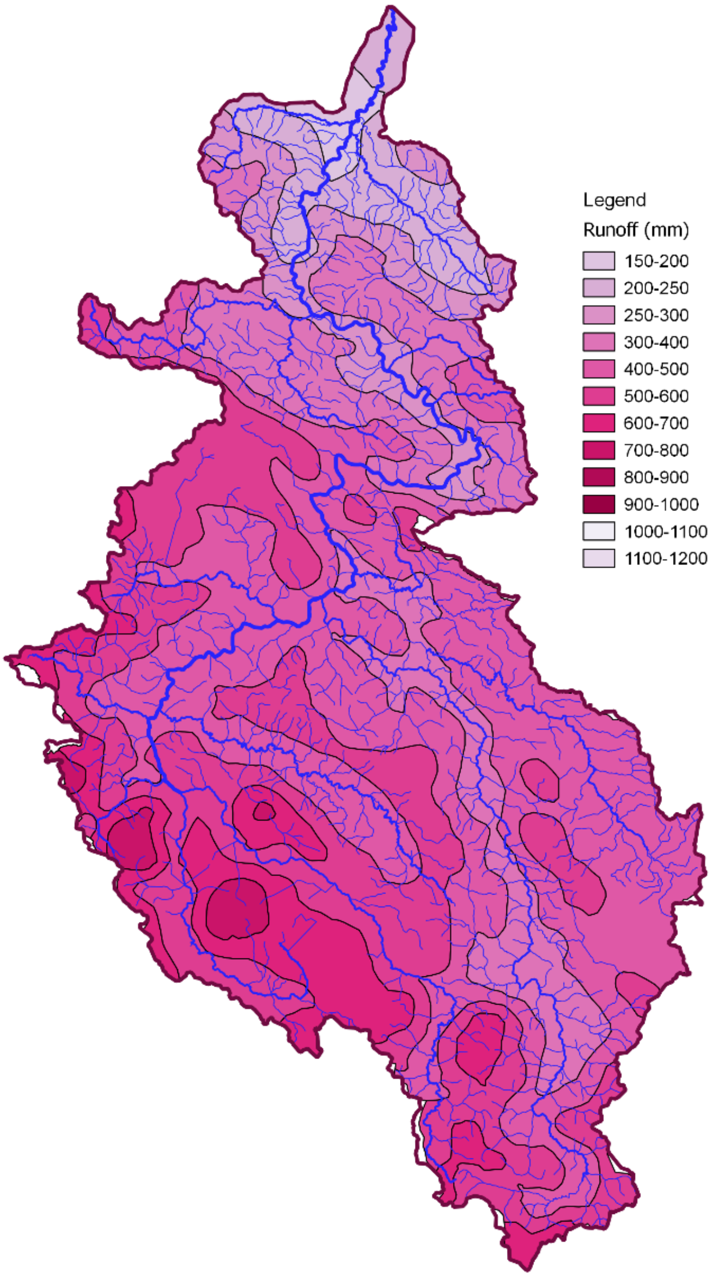
parts, maximum rain falls in the late autumn and the minimum during the summer months. The warmest month is July and the coldest is January.

Snow cover significantly impacts the Drina River water regime due to large amounts of water accumulated in it, with the highest flows recorded in springtime, in April and May.

3.5 Runoff

The average discharge at the confluence to the Sava River is about 370 m^3/s which results in the long-term average unit-area-runoff for the complete catchment of about 18.5 $l/s{\cdot}km^2$.

The runoff in DRB is unevenly distributed – it is very high in the mountains, while the contribution of the northern part of the catchment to the Drina River flow is less significant.

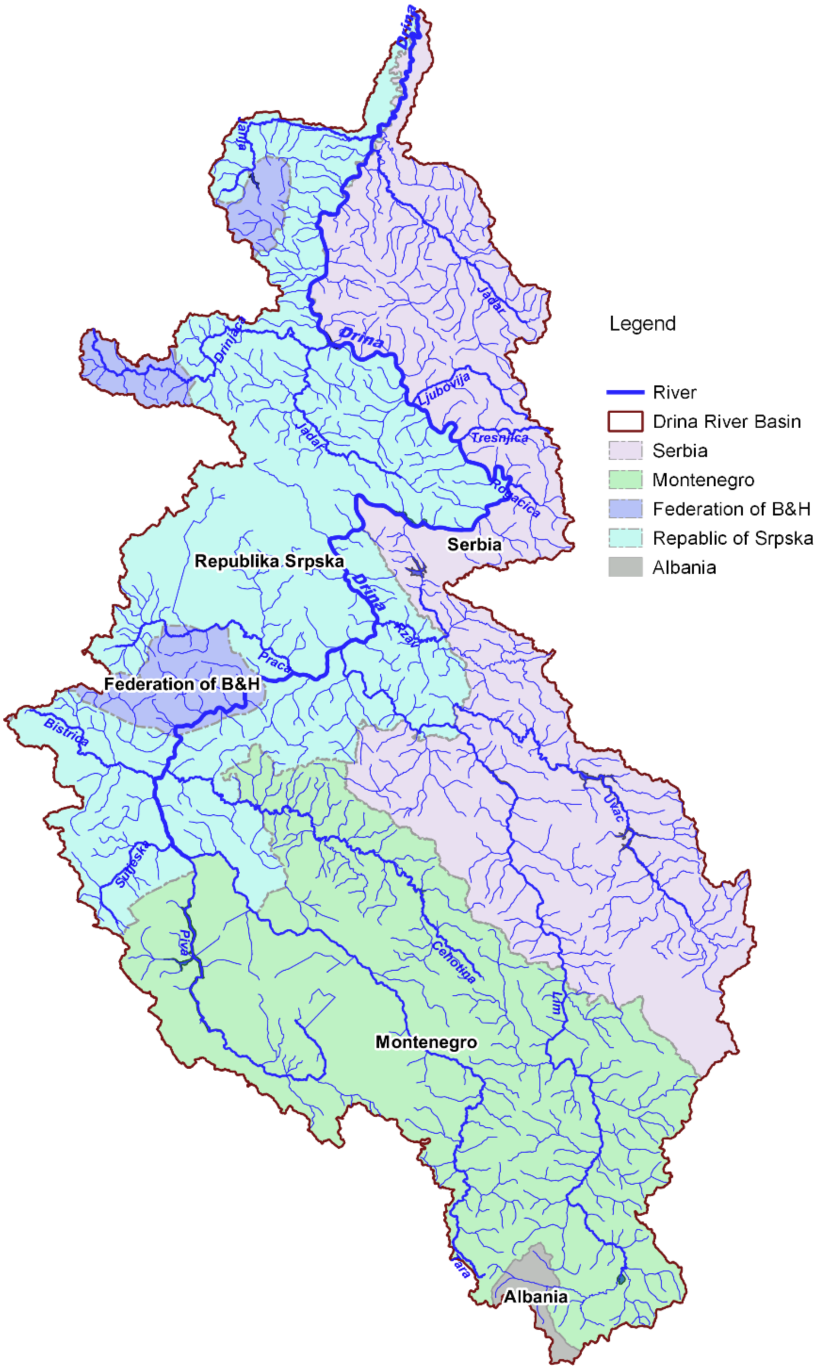


Runoff in DRB

3.6 River network

The Drina River basin has a dense hydrographic network. The two source-rivers of Drina River in Montenegro are Tara River (sub-basin area of 2,006 km²), and Piva River (1,784 km²) which merge at Šćepan Polje at the Bosnia and Herzegovina /Montenegro border. Some details on these rivers are given bellow.

The Drina River reaches the confluence with the Sava River at an altitude of 78 m a.s.l. on the Pannonian Plain (Semberija and Mačva) after a length of 346 km and a height difference of 350 m a.s.l. (equivalent to an average 1% slope).



Hydrographic network of DRB

The Piva River

The source of the Piva is the river Tušina that flows in the direction of Dinarides. Northwest of the village of Boan, Tušina enters the limestone valley about 300 m deep and connects with Bukovica stream which comes from the north. Further to Šavnik the main stream is called Bukovica. Downstream of Šavnik, the river joins the Bijela River coming from the southeast. From this point towards northwest, up to the joint with the Komarnica River, the main watercourse is called Bijela River. The Bijela River than inflows into the Komarnica River, coming from the north, from the southern slopes of Durmitor. Upstream of the Bijela River mouth, the Komarnica River created a canyon with depth over 600 m. After merging with Vrelo Pive, the river is named the Piva River.

The largest tributary of the Piva River is Sinjac, once originating from the largest karstic spring of Montenegro (the Pivko oko, with an average capacity of over 20 m^3/s). This spring is now submerged in the Piva reservoir (Mratinje). On the mouth of Sinjac, the Piva River turns and continues to flow north. Left tributaries of the Piva river are Vrbnica and Mratinjska River. Downstream of the Mratinjska River mouth, in a canyon, stands a dam of Piva reservoir (volume about 800 Mio m^3).

The canyon of Komarnica
(Source: https://www.parkpiva.com/listing/kanjon-komarnice/)

The Piva lake (reservoir of HPP Mratinje)
(Source: https://de.wikipedia.org/wiki/Pivsko_jezero)

The Mratinje (Piva) dam
(Source: https://www.epcg.com)

The Piva downstream of Mratinje dam
(Source: https://www.bemytravelmuse.com/via-dinarica-trail-guide/)

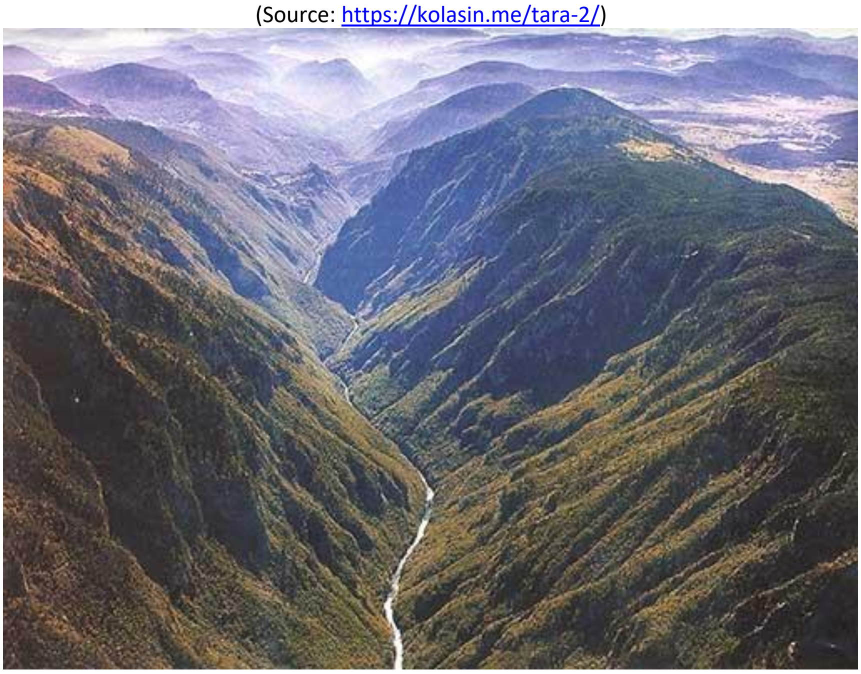
The largest part of the Piva River basin is on the territory of Montenegro, and only a small part in the territory of Bosnia and Herzegovina.

The Tara River

The Tara River emerges from the confluence of the Opasnica and Veruša Rivers in the Komovi Mountains and runs in the direction of the north to Kolašin. In this part of the basin, the riverbed is quite wide and flat with steep sides, while the river valley is wide and mild with rare rocky and even more rare pebbly terraces and dense river network. From Kolašin to Mojkovac, Tara still maintains the same course of flow with the characteristic four widenings: Kolašin-Baković, Trebaljevski, Sjorgorski and Mojkovacki, which are connected with three gorges: Trebavljeska vrata, Vagansko-strelačka and Gradačko-Bjelasička. Significant tributaries in this part of the basin are the right tributary Svinjača which flows from Bjelasica mountain and the left tributaries Plašnica and Šatornica from Sinjajevina mountain. Tara changes direction from Mojkovac and turns northwest flowing through the canyon valley until it reaches the Piva River. The most distinct canyon characteristics of the stream are in the part from the Dobrilovine monastery to the village of Bogomolje, where the canyon reaches a depth of 1550 m, while the altitude difference from the riverbed to the entry of the valley is about 1080 m near Tepac village.

The canyon part of the Tara River basin is characterised by exceptional natural beauties, so that the part of the stream from Bistrica to Šćepan Polje is a part of the Durmitor National Park.

The Tara River valley near Kolašin
(Source: https://kolasin.me/tara-2/)



The Canyon of Tara River
(Source: https://highlandertim.com/en/destinations/tara-canyon/)

The Tara River near the junction with the Piva River
(Source: https://www.parkpiva.com)

The largest part of the Tara River basin is located in Montenegro, and only a small part on in Bosnia and Herzegovina. The Tara River joins the Piva River at the border of the Bosnia and Herzegovina - Republic of Srpska and Republic of Montenegro in the area of Šćepan Polje village, near Hum, forming the Drina River.

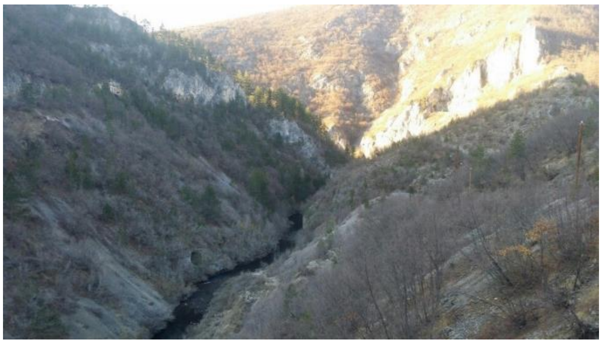
The Ćehotina River

The Čehotina River springs under the mountain of Stožer (1576 m above sea level) and as the other right tributaries of the Drina River, flows southeast-northwest. After the Lim River, it is the largest tributary of the Drina River. The upper part is in a narrow and deep valley, which later spreads out of the gorge into the spacious Pljevaljsko field. Downstream from Kamenica to the mouth of the Drina River near Foča, the Ćehotina River flows through the canyon.

The Otilovići dam was constructed upstream from Pljevlja, for the needs of the thermal power plant. The reservoir volume is relatively small.

Right below city of Pljevlja the Ćehotina River receives the Vezišnica River at the left side and the Voloder River above the Gradac settlement. There are several springs in the Ćehotina riverbed that affect its water balance.

Most of the catchment area of Ćehotina is located on the territory of Republic of Montenegro and a smaller part on the territory of Bosnia and Herzegovina. Its course in Montenegro is 100 km long, and in BiH is 25km.



Ćehotina River valley
(Source: https://foursquare.com/v/brana-otilovici/)

Meanders of the Ćehotina River in Otilovići reservoir
(Source:https://www.poslovnivodic.com/turisticka-organizacija-pljevlja.html)

Otilovići Dam
(Source: https://www.vijesti.me)

Downstream reach of Ćehotina River (BiH)
(Source: https://it.wikipedia.org)

The Lim River and tributaries

The Lim River is the largest tributary of the Drina River. The upper part of the catchment belongs to Montenegro, while the middle and lower parts are shared by Serbia and the Bosnia and Herzegovina (Republic of Srpska).

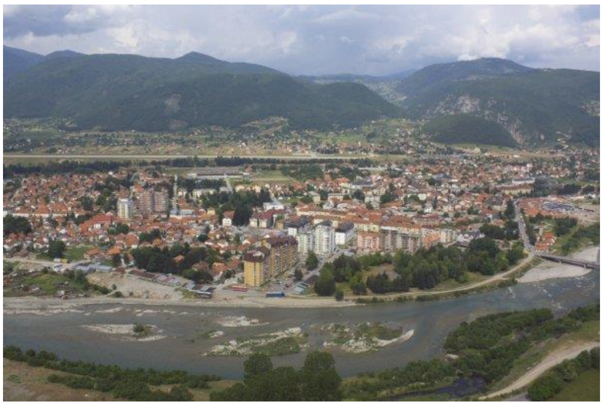
Lim outflows from the Plavsko lake that receives the water from the Ljuča river, which originates from the mountain streams of Vruja and Grnčar from Prokletije mountains.

Lake Plav
(Source: https://www.itinari.com/national-park-prokletije-pbtt)

The geological composition of the Lim River valley is diverse and consists of rocks of different ages. The Lim River entirely runs through gorges and valleys, depending on the terrain composition. In the limestone area, the valleys are narrow with high valley sides and in other parts they are more extended. The river valleys are widest in the upper part of the stream, narrowing downstream and forming the gorge at the very downstream part. The largest valleys are: Plavsko-gusinjska, Murinska, Beranska, Zatonska and Bjelopoljska.

Significant tributaries of the Lim River are: Zlorečica, Šekularska, Trebačka, Lepešnica, Ljubovđa, Lješnica, Bjelopoljska Bistrica, Mileševka (in Prijepolje, with the catchment area of 154.25 km^2), Seljašnica (70.28 km^2), Bistrica and Uvac.

In the lower part of the catchment, just behind Prijepolje, a reservoir of about 44 Mio m^3 is formed for the Potpeć HPP. The derivation HPP Bistrica that uses water from the Radojnja reservoir is located on the reservoir's right bank, near the town of Bistrica. The Potpeć reservoir is its compensation storage area.



The Lim River in Berane (MNE)
(Source: https://en.wikipedia.org/wiki/Berane)

The Lim River near Bijelo Polje (MNE)
(Source: http://www.tobijelopolje.me)

Lim River in Prijepolje (RS)
(Source: https://prijepoljeinfo.rs/)

Reservoir of HPP Potpec
(Source: http://srbijauslici.blogspot.com)

The Lim River upstream of Priboj (RS)
(Source: https://www.2bike.rs/albumi)

The canyon of the Lim River near the mouth
(Source: https://commons.wikimedia.org)

Downstream of Priboj, the Lim River receives its largest tributary, the Uvac River. In its further course it descends to the Drina River valley and enters the Drina River near Medjedja. The border of the Republic of Serbia Bosnia and Herzegovina (Republic of Srpska) is at Rudo.

The spring part of the Uvac River is located on the eastern part of the Drina River basin, receiving waters mainly from the mountains: Javor, Golija and Zlatar. The Uvac River catchment is elongated in shape and has a specific character due to its different topographic and morphological characteristics, so that the entire catchment can be divided into three separate parts.

The upper part of the catchment extends to the town of Krstac, where the Uvac and the Vapa Rivers are merging. This part of the catchment is mostly formed of a spacious Sjenica plateau at an altitude of 1000-1400 m a.s.l. The plateau is mostly formed in the karstic limestone through which most of the waters subsides and probably flows down to the spring of the Raška in the Ibar River catchments. As a result, this part of the basin has relatively small runoff in relation to the catchment areas of the Lim and the Drina Rivers, but the plateau has retention capabilities for high waters mitigating, especially during the spring due to the snow melting.

The Vapa River
(Source: http://www.putokaz.me/u-svijetu/1839-rijeka-vapa-okolina-sjenice-srbija)

The Uvac River within Uvac HPP reservoir
(Source: http://avanturista.co)

The middle part of the catchment extends from the Radojnja River catchment to the Uvac and Vapa confluence. It is characterized by a very deep riverbed of the Uvac River and its tributaries. The slopes are steep, flow is rapid and fast, which gives an extremely torrential character to this area. On the part of the stream near Sjenica the HPP Uvac was built in 1979, with a 213 Mio m^3 reservoir. There are two more reservoirs downstream: Zlatarsko lake (270 Mio m^3) with HPP Kokin Brod and Radojnja (7 Mio m^3), with the derivation power plant Bistrica.

Zlatarsko lake (Kokin brod)
(Source: https://sr.wikipedia.org/wiki/)

Radoinja lake
(Source: http://www.serbia4youth.org)

The lower part of the catchment covers the area from the confluence of the Uvac and Lim Rivers to the Radojnja village. This part of the catchment is characterised by deep valley, without significant tributaries. The most significant feature of this area is the large stream gradients causing a large altitude difference of about 400 m between the Uvac and Lim riverbeds and allowing the Uvac River flow to be impounded and transferred into the Lim River for the hydropower production. The entire basin is located on the territory of the Republic of Serbia.

Other tributaries

The Drina river tributaries influencing its water regime are: the Sutjeska, Bistrica and Prača Rivers (left tributaries on the territory of Bosnia and Herzegovina), the Rzav River (right tributary, originating from confluence of two headstreams called Beli and Crni Rzav, entering into the Drina River near the city of Višegrad, 72 km long), Drinjača (left tributary in the area of HPP Zvornik

reservoir), the Janja River (left tributary on the lower part of the Drina River) and the Jadar River. All tributaries except Janja and Jadar, flow into Drina in the upper and middle part of the watercourse and have torrential character.

The Jadar River is the largest tributary of the Drina on the lower course. Its entire catchment is located on the territory of the Republic of Serbia (878 km^2, 73 km of the total length). Significant tributaries of the Jadar River are Lešnica (100 km^2), which is connected to the Jadar River by a channel, Korenita (66 km^2), Likodra which is formed by the Bogoštica and Čađavica Rivers in Krupanj and receives the water from the Belocrkvanska River (the area of the catchment 63 km^2) just before it enters into Jadar.

Two smaller right tributaries flow into the Drina River between the Jadar River and the city of Loznica: the Krivaja and the Žeravija River (24 km^2). Two right tributaries are flowing through the city of Loznica: the Štira River (42,0 km^2) and the Trbušnica River. Two small streams (Ciganski and Simića stream) are entering the Drina River in Banja Koviljaca.

Canyon of Beli Rzav
(Source: https://palisad.rs/)

Upper part of Drinjaca River
(Source: https://mapio.net)

4. CHARACTERISTICS OF DRINA RIVER CHANNEL

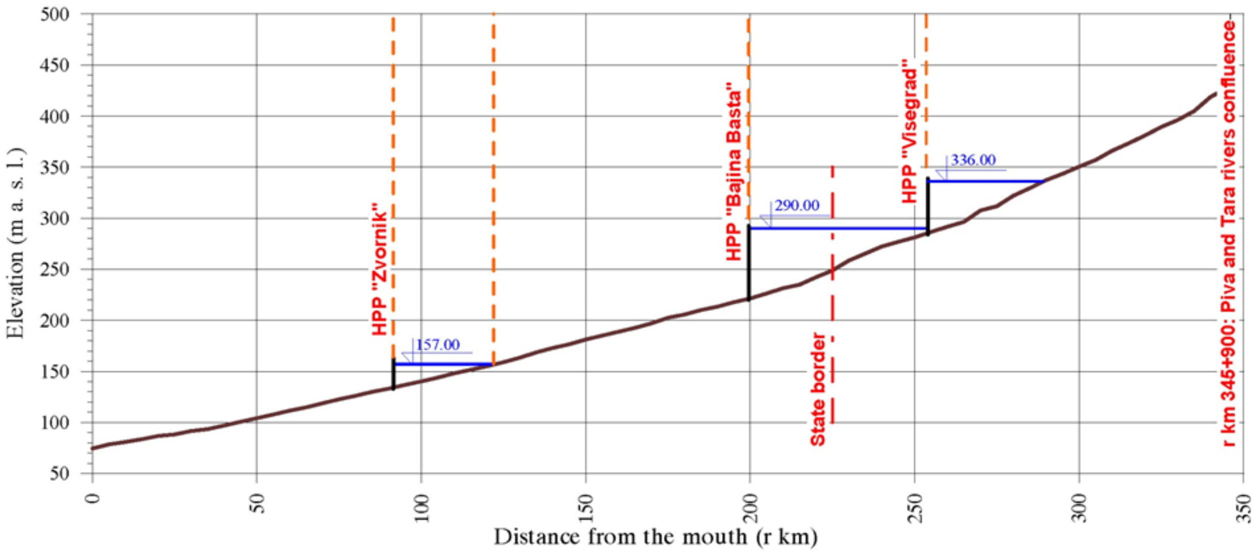
4.1 General division of the DR channel

The total length of the Drina river is about 345 km, with an average slope of 1.03°/₀₀. It can be divided into three parts based on the discharges, slopes and the catchment shape: upper, middle and lower flow.

The Upper Drina, from Šćepan Polje (confluence of the Tara and the Piva Rivers) to the mouth of the Lim River, is about 82 km long and has a total slope of 134 m during low water. The slopes of the section range between 1.5 and 1.9 °/₀₀, and average is about 1.63 °/₀₀. The area of the catchment is 13,714 km^2, which makes up 68% of the total catchment size.

The Middle Drina includes a section from the mouth of the Lim River to city of Zvornik and is about 173 km long, with a total altitude difference of 161 m. Slopes are slightly milder on this section and range between 0.5-1.35°/₀₀, and the average is 0.93°/₀₀. The catchment area of the middle flow is 4,172 km^2 (21%).

The Lower Drina stretches from Zvornik to the confluence with the Sava River and is of about 91 km long. The riparian area are the plains called Podrinje, Mačva and Semberija. The total slope of the section is about 60 m. Slopes range from 0.5-0.7°/₀₀ during low flows. The catchment area of this part is 2,195 km^2 (11%).



Longitudinal profile of the Drina River with the existing HPP reservoirs

Beside this general division, there are some very specific short river stretches, presented below.

4.2 Description of river characteristics

4.2.1 Drina River between Sastavci and Foča (section length 23.5 km)

The entire length of this section is in a gorge, cut into rocks of mostly sand and shale stones. The river flow in the solid and rocky riverbed with numerous obstacles is irregular, with large variation of velocities.

There are as many as 25 steep parts, where the water fall reach 4.5 ‰. The width of the river is mainly 40-50 m. The width of the valley varies considerably, it is mostly a gorge type, with occasional parts several hundred meters wide (at the confluence of Sutjeska, Brod, Foča). The riverbed is unchangeable due to geological composition of the terrain.

This section is located on the territory of Republic of Srpska.

Rafting on Upper Drina
(Source: http://058.ba/)

Mouth of Ćehotina into the Drina in Foča
(Source: http://058.ba/)

4.2.1 Drina River stretch from Foča to Višegrad (section length 68 km)

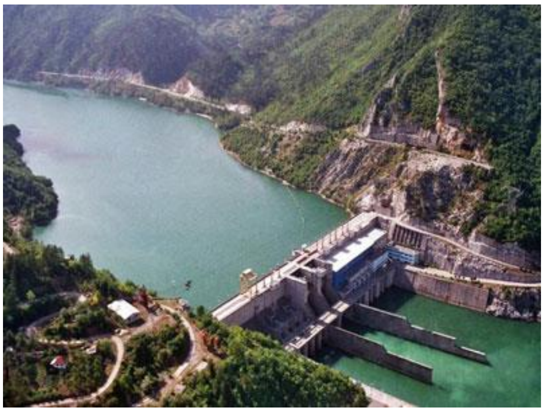
The section encompasses a part of the Upper Drina to the mouth of Lim and part of the Middle Drina to Višegrad. The geological composition of the section is similar to the upper one. The gorge is carved in limestone rocks, and has only sporadic wider sections, most often at the confluence of individual tributaries.

Similar shape of the river valley and significant slope of the riverbed are characteristic for the Middle Drina. The width of the riverbed, mostly carved into rock, is usually 50-60 m, with significant sporadic extensions. Near Goražde, the width of the river is over 100 m, while in narrow parts it is only 20 m.

On this section, in the Goražde-Ustiprača zone, the largest energy potential of the upper Drina is concentrated, in a 28 km long gorge. This is where HPP Višegrad dam was built.

Most of this section of the Drina River is on the territory of the Bosnia and Herzegovina -Republic of Srpska, except on the section Goražde - HPP Višegrad dam, where the Drina flows through the territory of the Federation of Bosnia and Herzegovina.

Canyon of the Drina River
(Source: http://martinmeyer.de)



The Višegrad dam
(Source: https://www.akta.ba/resources)

4.2.1 The Drina River stretch from Višegrad to the HPP Bajina Bašta (section length 55,4 km)

The river valley at this stretch is also mountain-gorge type, and it is cut into a rock massif with sporadic extensions. Going downstream the valley is expanding. Sporadic extensions (up to 500 m in the upper part) are wider downstream from the Klotojevci, reaching up to 2 km.

The river valley from Višegrad to the mouth of the Drinjača River is formed in very cracked Paleozoic rocks, prone to erosion, and the river receives considerable amounts of sediment.

This section contains the longest gorge on the entire Drina River (35 km). The largest energy potential is located here and used by HPP Bajina Bašta (located 14.5 km upstream from the Bajina Bašta settlement). Its reservoir is impounding the entire river stretch up to Višegrad.

Drina River in Višegrad
(Source: https://visegradturizam.com)

A narrow part of the Perućac lake (reservoir of HPP Bajina Bašta)
(Source: https://tara.rs/)

Perućac lake
(Source: https://banjeusrbiji.com/jezero-perucac/)

Perućac (Bajina Bašta) Dam
(Source: https://www.wikidata.org)

4.2.1 The Drina River stretch from the HPP Bajina Bašta to Zvornik (section length 105,1 km)

On this stretch the Drina generally maintains the characteristics it had in the upper course and part of the middle course. It is still a mountain-type river with significant slopes, valleys cut into rock massifs, with sporadic extensions and alluvial plains. However, all these characteristics are gradually changing going downstream, where there are significantly different characteristics. Widenings are more frequent and wider, slopes are declining gradually, gorges are no longer as frequent and distinct as in the upstream stretches. The whole relief becomes milder. The river valley on this section is mainly cut into the Palaeozoic rock mass, to the mouth of Drinjača, while downstream to Zvornik limestone is predominant. This composition of the valley causes significant amounts of sediment deposits from the basin and its transport to the Zvornik reservoir. The entire river reach up to Zvornik is characterized by a clearly distinctive cutting of the river valley and significant erosion in large parts of the catchment area, which results in significant amounts of sediment deposits in the valley, its transport downstream and deposition on the sections where the bottom shear stress weakens.

On this section, the river still has considerable energy potential, especially the section around Rogačica, Ljubovija and Zvornik. A smaller part of this potential was used by the HPP Zvornik, the first major hydropower plant on the Drina River.

Widenings of the river valley around Ljubovija and other settlements reach width of 2 km. The last dangerous whirlpools on the Drina River are located on this section. The riverbanks in the lower parts are particularly unstable, there is a erosion during high flows, and islands and sediment bars are becoming more common. There is no major meandering, but the riverbanks are sporadically endangered, especially on mouths of larger torrential tributaries. On this section, the Drina River receives water from the Drinjača River, and from smaller ones such as the Pilica River near Bajina Bašta, the Rogačica River, the Ljuboviđa River near Ljubovija etc. The mouths of these tributaries are not fixed, so sometimes the torrential erosion endangers the populated areas near the watercourse.

Larger settlements are relatively frequent on this section (Bratunac, Srebrenica and Zvornik on the left bank and Bajina Bašta, Ljubovija and Mali Zvornik on the right bank). Bajina Basta is 1-

2 km away from the Drina, located on the plateau at 229,7 m asl, high above the riverbed. Ljubovija is located at the altitude of 175,9 m asl, at the foot of the hill and at a distance of about 600 m from the Drina riverbed. This settlement was previously located 2 km downstream, on the riverbank, but historical flood in 1896 destroyed the settlement and forced people to leave.

Drina River near Bajina Bašta town
(Source: https://mapio.net)

Drina River near Ljubovija
(Source: https://peratravel.blogspot.com)

Zvornik lake
(Source: http://lakesofserbia.blogspot.com)

Zvornik Dam
(Source: http://lakesofserbia.blogspot.com)

4.2.1 The Drina River from Zvornik to the confluence with the Sava River – Lower Drina (section length 91 km)

The section downstream from Zvornik is fundamentally different from the upstream sections by many parameters. A river that had a narrow valley, a relatively fixed riverbed formed in hard materials and a significant slope, suddenly becomes a lowland river.

Instead of solid materials, as in the upper and middle sections, the riverbed is cut into the soft deposits of former Neogene lakes, which, going downstream, gradually transforms into the Sava River alluvial plain.

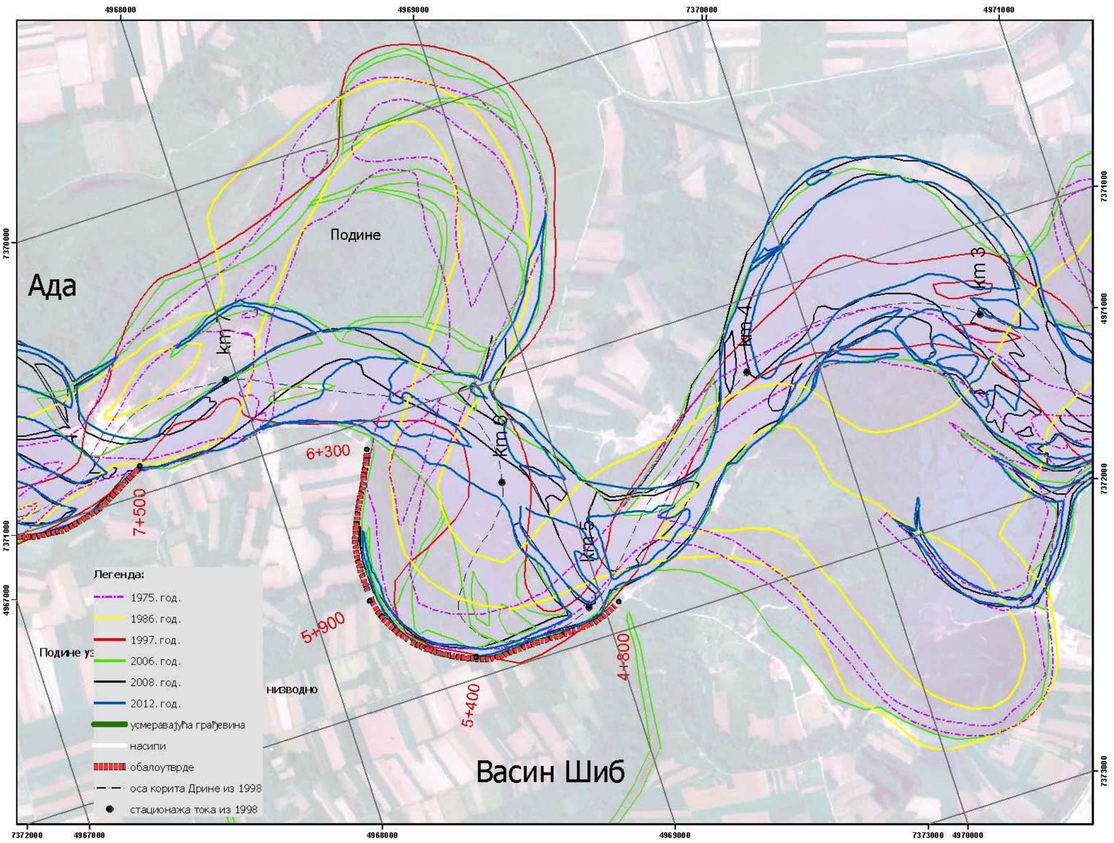
The Drina riverbed has very uneven characteristics: it is very wide in some places (up to 300 m), with numerous river islands and sandbanks, while narrow and seemingly stable in other. The instability of the riverbed and the fragmentation is increasing downstream.

Downstream of Banja Koviljača and Loznica all the way to the confluence with the Sava River, the Drina River has numerous meanders, curves, river branches and temporary riverbeds often changed by spilling out and shifting planform in a very wide area. The slope is small, the river is

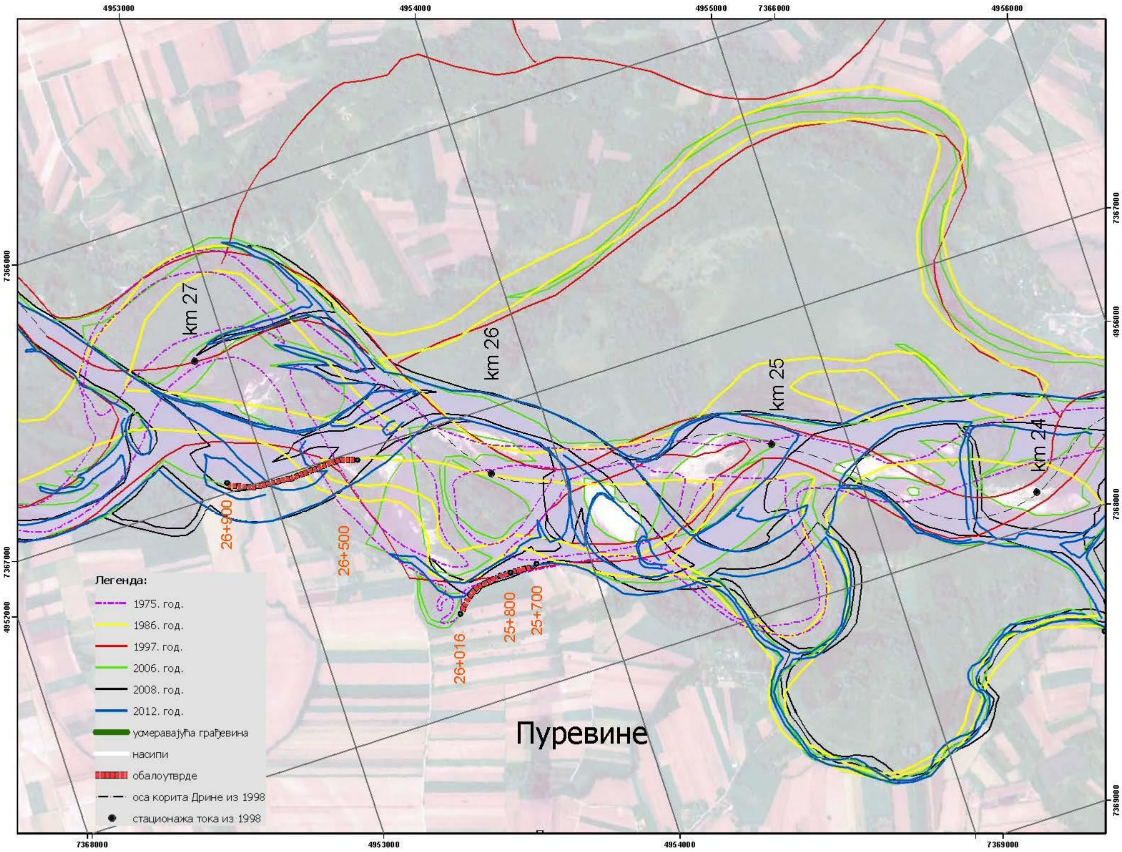
relatively slow and shallow, full of sandbanks, shallows and gravel and sand deposits that are very unstable.

Lower Drina, unlike the upstream reaches where the riverbed is cut into rocks, is a typical alluvial reach where the river curved its bed in its own sediment deposits. The riverbed is unstable and braided, with numerous meanders, abandoned arms, river islands and sandbars. The meander belt is 2-3 km wide.

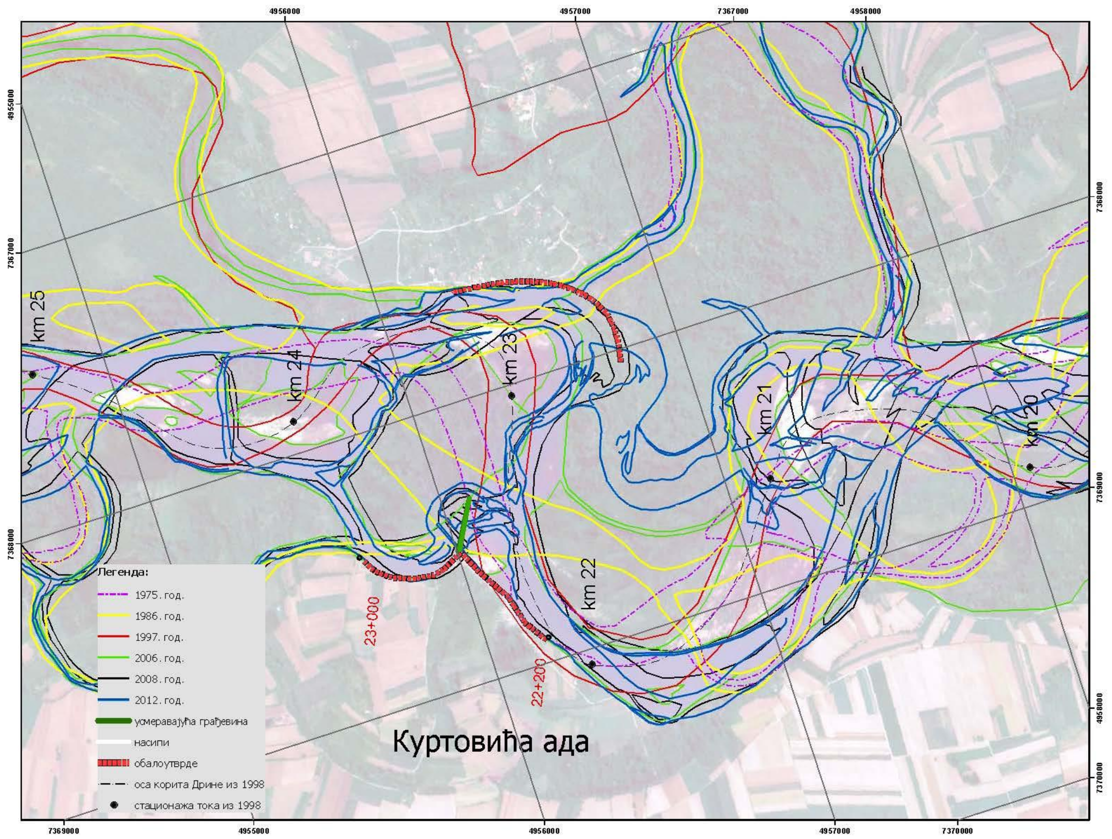
The development of the riverbed is very irregular and dynamic. The main river bed is relatively shallow and winding, and has relatively small capacity. New branches and cut-offs are developed during high water, with frequent erosion of river banks which leads to the degradation of agricultural land, and also endangers nearby houses and communications.



Changes to the Drina river route in the "Vasin Šib" sector, 1975-2012 (Source: JCWI)



Changes to the Drina river route in the "Purevine sector", 1975-2012 (Source: JCWI)



Changes to the Drina river route in the "Kurtovica ada sector", 1975-2012 (Source: JCWI)

Manifestations of fluvial erosion are very visible and intense, and banks may shift for tenth of meters in a very short time. Erosion of outer banks is present on almost all curved reaches. The sediment deposition in the form of large sediment bars is a parallel process on all inner banks.

Large sediment bars in the Drina riverbed (Source: JCWI)

The extreme instability and irregularity of the development of the Lower Drina riverbed is a result of to the irregularity of hydrological and hydraulic characteristics of the stream, the geological composition and geomechanical characteristics of the terrain (alluvial deposits 12 m thick), the sediment regime (the upstream Zvornik dam completely interrupted the bed load inflow into this section), the exploitation of sand and gravel from the riverbed, and various structures in the riverbed which influence the flow pattern.

The coastal areas are wide, cultivated alluvial plains of Semberija on the left and Mačva on the right side. It should be noted that, due to the flow direction from south to north, the right bank is eroded in most cases.

It can be concluded that the Lower Drina is still is in the development process. This development is significantly disturbed by the construction of reservoirs, mostly for the HPP Zvornik, which traps considerable amounts of river sediments. Under these conditions, the river moves and takes the sediments from the riverbed and coastal terrains, which results in significant erosion of the coast and the drift and degradation of the riparian land complexes.

5. ANALYSIS OF EROSION PROCESSES

Soil erosion and torrents are two interconnected natural phenomena, each in its own way causing enormous damage in all spheres of life and economic activity in DRB. Erosion processes are long-term, with visible changes within a one year to several decade period, while torrents occur and end in a relatively shorter period.

The intensity and surface distribution of certain forms of erosion in DRB have been subject to monitoring and study for decades, but not in continuity.

The erosion map is an important document as it clearly identifies areas that, from the aspect of threatening erosion, are erosion-prone or erosion risk areas, for which constraints and conditions of use are defined, preventive measures are prescribed and required erosion control work is performed as a priority, meaning that it is important to have updated maps.

5.1 Factors of erosion in DRB

The relief of the DRB surface is formed primarily by a combination of tectonic and sedimentary processes, glacial movements and other processes. DRB geological substrate has, over time, been the result of various combinations of the above geomorphological phenomena, which, for convenience, are called "tectonic" and "erosion" geomorphological processes.

Soil erosion is a natural phenomenon, but also a process whose intensity is most influenced by the overall activity of people, and this is the only area that can be controlled by changing the way land is used to reduce the intensity of erosion to a tolerable extent.

Anthropogenic effects on erosion processes are reflected through deforestation and destruction of forests, irregular agrotechnical measures, intensive grazing and livestock breeding, uncontrolled urbanization and industrialization, unplanned opening of quarries, etc.

Land loss caused by erosion processes is one of the most current problems in the DRB, and land loss assessment and anti-erosion measures are of strategic importance for ecosystems, water management, economy, spatial planning and the environment. The erosion process can be very quick, but the consequences are long-lasting (it takes 200-1000 years to rebuild the 2.5 cm surface layer under vegetation conditions).

Present depopulation trends in DRB represent an indirect anthropogenic factor, which reduces the intensity of erosion. Aging and depopulation of rural settlements, migration village to town, marginalization of agriculture and reduction of livestock lead to land use changes and gradually restrain erosion processes.

The products of erosion processes in the basin is an erosion deposit that reaches the river network and is transported to the lower parts of the basin causing damage to agriculture (removal of semi-arable land), water management, energy (reduction of useful volume of reservoirs due to backfilling) and other branches of the economy.

In addition, erosion processes negatively affect the environment in two ways - directly and indirectly. The direct (on-site) effect is reflected in the removal of land, the stripping of rocks and the creation of rocky deserts where the development of any flora and fauna is not possible. The indirect (off site) environmental effect of erosion processes is reflected in the washing away of harmful substances (chemical pollutants) that are transported together with the erosion layer.

Some examples of erosion processes in the Drina river basin are presented bellow.

Erosion process as the consequence of unregulated slopes of the road

Tearing away the area under the vineyard

Erosion deposition from the Prokletije mountain slope

Fluvial erosion in the riverbed of the Ljuča river

Rocks without vegetation on Mount Visitor as a consequence of anthropogenic factor

Fluvial erosion in the riverbed of the Ljuča river

Sediment deposition at the Likodra river

The riverbed of the Brštica, tributary of Likodra river, is covered with sediment

Production of sediment in river basins and its transport in watercourses are two components of the natural global process. High intensity of erosion processes also affects the genesis of high water in torrential river basins, increasing the maximum flow rate.

5.2 Present erosion and torrents related problems in DRB

The present regime of sediment in DRB is conditioned by the anti-erosion measures in the basin and the construction of structures in the river beds. The most important structures are dams that, in the backwater area, have altered the natural conditions of water and sediment flow.

Regulation of torrents in DRB began in the early XX century, primarily with the aim of protecting railroads. Between the two WW, a program of anti-erosion measures started, aiming not only on protection of railroads and roads. In 1930, the Yugoslav law on the regulation of torrents came into force. It was implemented during and after the II WW, until the enactment of new legislation in 1952 and 1954.

In 1954, the Erosion and Torrential Protection Act came into force. For the implementation of the planned works and measures for the regulation of torrents and erosion protection, regional organizations - "Sections for erosion and torrents" have been established.

In the period up to 1980, a considerable amount of work was carried out, both for the immediate protection of the reservoirs built during that period, as well as for the protection of roads and industrial facilities. There are several groups of works by purpose:

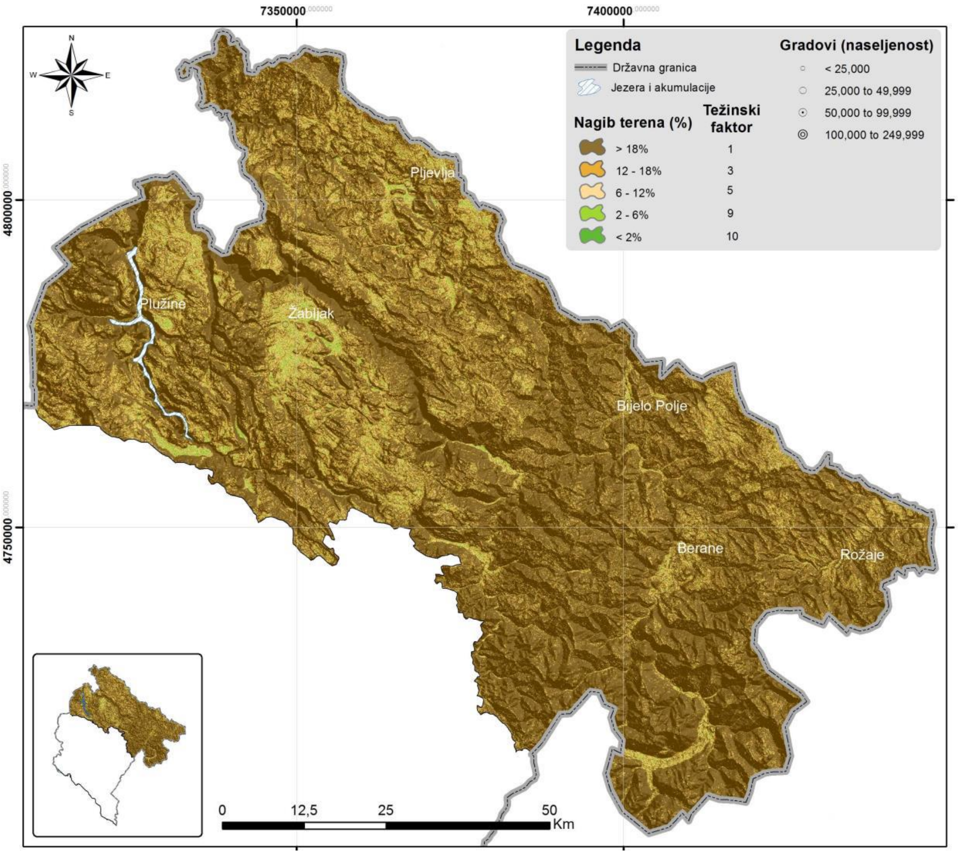
- protection of railways and roads (the largest volume of works was performed for the protection of the Belgrade-Bar railway line);
- protection of HPP reservoirs on the Drina;
- protection of settlements along the Drina River (Zvornik, Ljubovija, Bajina Bašta, Visegrad, Goražde, Loznica and others);
- protection of large industrial facilities in Loznica, Zvornik, Gorazde, Visegrad, Prijepolje, Bjelo Polje and other settlements.

Those were complex anti-erosion works and measures, combined with the regulation of torrential flows.

5.2.1 Montenegro

Soil erosion is a natural process that in Montenegro causes environmental changes such as land degradation, land loss, water pollution and ecosystem change. Water erosion affects 95% of Montenegro. The rest of the area is characterized by alluvial accumulation, where sediment deposition also affects agricultural land. The large accumulated sediment flows dominate the river basins, and are the consequence of erosion of land, and as such create a major environmental problem. The key to understanding the impact of land management in the future and climate change on land degradation is in modeling the rate of soil erosion under different land uses. The topography of the region is illustrated by the percentage of slope of land within the river basin (Figure 1).

Water erosion is dominant in high slope terrain due to complex physical and geographical conditions associated with tree felling activities. The average annual soil erosion intensity is estimated to be higher than 10 tonnes per hectare (*Blinkov, I. (2015)*) .



Land slope in the DRB within Montenegro (%)

A study conducted in the Polimlje area *(Spalević, V. et.al., 2013)* concludes that vegetation cover conditions and land use have influenced the development of erosive processes in the river basin. The total loss of land in the area covered by this study is estimated to be 315 m^3 per km^2. This indicates that they belong to the 5^{th} erosion (Gavrilovic,1972). However, the strength of the erosion process is considered medium, and by type of erosion, represents mixed erosion. The change of land use in the structure for the period of 4 decades (1970-2013), in the area that was the subject of this study, reduced the intensity of soil erosion by 3.95%.

The latest studies on soil erosion processes in the Danube basin (Polimlje area - 40.23 km^2) were conducted in 2016. The IntErO computer-graphic model was used to calculate the intensity of soil erosion, taking into account the data contained in the Forest Management and Management Plan, the Cadastre, the Landsat Program and the Statistical Yearbook. The total land loss was calculated to be equivalent to an annual loss of 327m^3 per km^2.

The highest rates of erosion of the soil in the Danube basin at the end of the consequences are (i) loss on farms, higher production costs and lower revenues at the farm, and (ii) an elevated concentration of phosphorous in the fresh surfaces, which negatively affects the quality of the water.

The specificity of the Drina River basin in the territory of Montenegro is that on a relatively small surface very diverse forms of erosion forms and specific torrential flows occur. Each of these phenomena required the adaptation of the usual methods for the erosion and torrent remediation to the specific situation on the terrain and finding new solutions suitable for the specific task.

Due to extremely high mountainous terrain, roads have been placed along the rivers and streams along which settlements and towns were built.

Each tributary of the Drina, in its upper reach, and some along its entire length, is a torrent which threatens nearby buildings and infrastructure.

Technical measures with the influence on retention and stabilization of sediment transport are dominant, while biological measures were less represented.

A large amount of anti-erosion and torrential flood protection works was done so far in DRB in Montenegro, and contributed to a significant reduction of torrential floods. Unfortunately, the maintenance of these systems is lacking, and this causes their gradual degradation and even partial destruction. Structures built in torrents are exposed to permanent destructive effects of torrential waters. There are numerous examples of the demolition of well-constructed structures due to poor or completely inadequate maintenance.

Works on the regulation of torrential flows have not ceased, although they have been considerably reduced in scope and limited to solving local problems as protection of cities and roads.

Existing registers and cadastres of torrential flows are more than thirty years old and have not been supplemented with new data since their creation, although many facilities have been built in the meantime, and changes in erosion intensities have occurred.

Much of the work on the regulation of torrential flows has not been registered, as they were carried out as part of the protection of the Belgrade-Bar railway and the roads along the Tara and Lima valleys.

5.2.1Serbia

Till 1991 a large amount of work on anti-erosion land management and torrent control was done in DRB. This led to the reduction of the average erosion intensity by one, in some areas by two

categories. The former erosion areas were afterwards used for highly productive agricultural production, especially for fruit growing.

However, the investments in new anti-erosion works and maintenance were significantly reduced in the last decades. As a consequence, frequent torrential floods occurred (Jadar, Stira, Ljubovija, Pilica, Raca - 2005, 2007, 2011), while the one with catastrophic consequences occurred in May 2014 on a large territory of Western Serbia.

Landslides and soil erosion during the 2014 flood

In the middle part of the Drina basin (between the Zvornik reservoir and the Bajina Bašta reservoir, during those years, anti-erosion works were made, from technical 50-100m^3/km^2 and biological 5-10ha/km^2. These are very small amounts of work, given that large the amounts of sediment run from these basins.

Over the last five years, investments in anti-aliasing work have increased significantly, so that the effects of those investments have already emerged. In the Jadar Basin, a tributary of the Likodra, a great deal of technical work has been done to stop the sediment. After the catastrophic floods of 2014, the town of Krupanj was flooded with large quantities of sediment launched from the Likodra River basin and tributary. Emergency measures and works from the projected 19, 12 landfill bulkheads were built to contain the sediment and already in 2017, after heavy rainfall and new torrential raids, the deposition in the basin was retained and the effects of the emergency works were successful.

Sediment retention dam in the Jadar River Basin

5.2.1 Republic of Srpska

The situation in DRB part in Republika Srpska has been in a very poor state for the last twenty years. Neither anti-erosion works have been invested in, nor care taken to ensure that structures that have already been built to protect against erosion and containment remain in a sustainable condition.

In the catchments of Janja, Drinjača, Prača, Bistrica and Bjelava, as large tributaries of the Drina River, no anti-erosion and biological and technical works have been done, which would greatly reduce the flow of sediment into the main recipient. The sporadic regulation of the bed (eg regulation of the Lamb in Bijeljina and Drinjaca through Šehovići) transports the sediment to the lower parts of the basin, but its production does not stop.

5.2.1 Federation Bosnia and Herzegovina

The hilly-mountainous character of the Federation of BiH causes the creation of a large number of torrents, as well as the possibility of creating new erosion processes. In the upper parts of the Janja, Drinjača, Prača river basins, due to uncontrolled deforestation, land degradation occurs and erosion processes occur (dredging and furrowing). Of the technical and biotechnical works, nothing has been done in these parts of the catchments.

5.3 Erosion in DRB countries

Data on erosion were compiled in GIS map and 5 erosion categories were further distinguished:

I - Excessive erosion - deep erosion process (gullies, rills rockslides and similar);

II – Heavy erosion - milder forms of excessive erosion;

III - Moderate erosion – medium surface, deep and mixed erosion (areas of degraded forests, degraded pastures, etc.);

IV – Slight erosion – lower intensity of erosion processes (forests, meadows and pastures on very inclined terrains);

V – Very slight erosion – areas without erosion or with traces of erosion.

5.3.1 Serbia

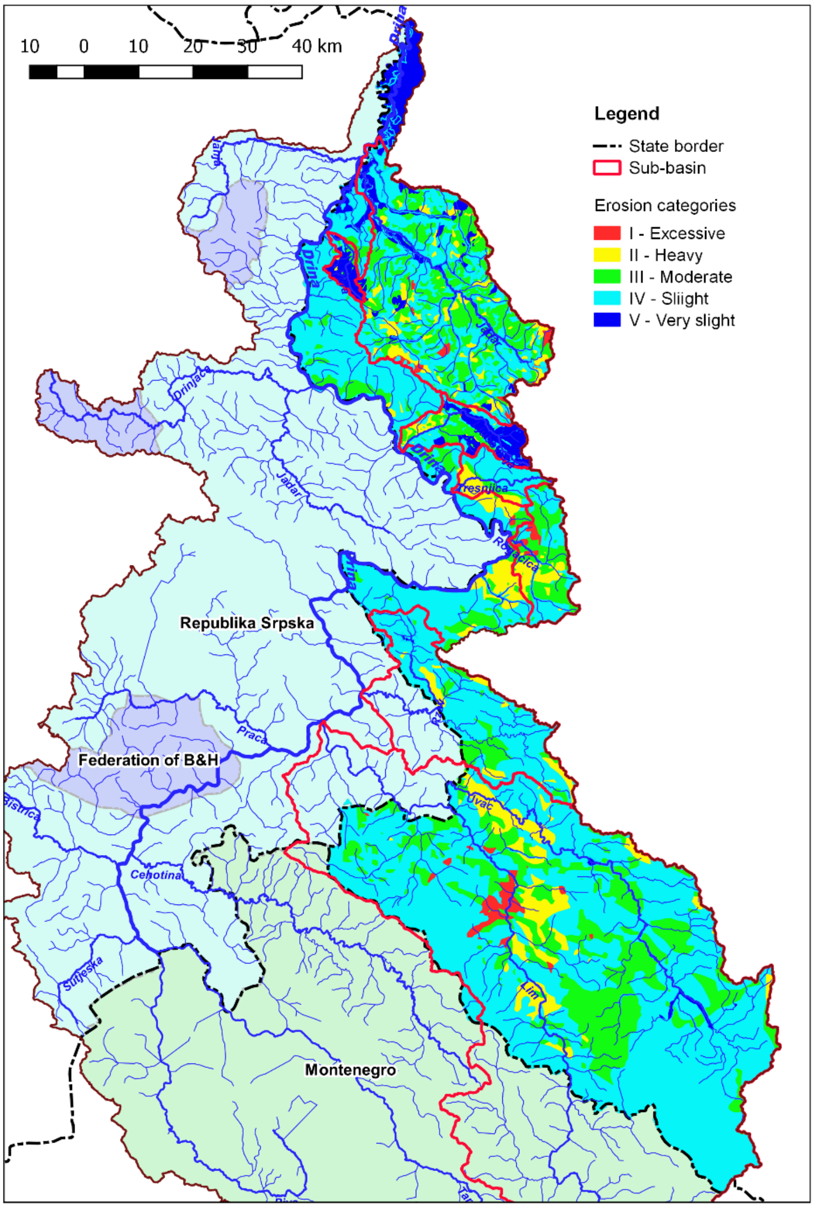
The map is produced using “Erosion Potential Method” (EPM), developed in JCWI. It is now a standard method for erosion mapping in water management in Serbia.

EPM method has been used to determine the erosion intensity and to calculate the erosion sediment yield and transport needed for water resources planning and management and hasn’t slope limitation. The method proved reliable for assessment of sedimentation that affects reservoirs, river channels, important structures and urban areas.

The basic parameter used to define the erosion intensity is the Erosion Coefficient (Z). Since erosion is a phenomenon occurring on the whole surface, the most rational presentation of the surface spreading of erosion is the mapping of the erosion. The mapping procedure requires

investigations and computations to determine and present on a map the surfaces with the same class Erosion Coefficient (Z).

The results of mapping revealed that in Serbian part of DRB very low and weak erosion are represented in the northern plains, while in the central and southern part of DRB erosion processes are of much higher intensity, with pronounced areas of strong and excess erosion. In central and southern parts, very weak erosion occurs only in the lowland areas, in valleys of the Drina River tributaries.



Map of erosion for DRB part in Serbia

Erosion categories in DRB part in Serbia

Category of erosion	I - Excessive	II - Heavy	III - Moderate	IV - Slight	V - Very slight
Participation	1.54%	8.85%	23.51%	59.10%	7.00%

Erosion on major sub-basins of the Drina River in Serbia

The Jadar River Basin

The Jadar River Basin is characterized by intensive erosion processes, with dominant category III and IV erosion, with significant participation of categories I and II. As a result of intensive erosion processes, floods of catastrophic proportions have occurred in the Adriatic Basin over the last two decades, especially in the municipality of Krupanj. The basic factors for the development of such processes are: geological substrate composed mainly of erodible rocks (sandstones, clay shales, etc.), soil composition (such as eroded pebble, brown acidic soil on sandstone, etc.) erodible, numerous short tributaries of large longitudinal falls that is, torrential tributaries. The most endangered part of the basin is the upper part of the basin, in the sub-basins of Likodra, Pecka, Lopatanjska, Crna reka and Močionik.

The Pilica River Basin

The Pilica River Basin is dominated by strong and medium erosion (II and III category). Hydrographically, the basin is very developed, with many tributaries of torrential character concentrated in the middle part of the basin.

The Ljubovića River Basin

The Ljubovića River Basin is most represented by very slight erosion, then medium, and strong. In hydrographic terms, the Ljubovića basin represents the entire system of torrential flows. Although most of the basin is made up of forests with approximately 60%, erosion is very intense in some locations. The most intensive erosion processes take place on agricultural land located on sloping terrain or on degraded forest areas.

The Trešnjica River Basin

The upper part of the basin is dominated by IV and V categories, where most of it is covered with forests. In the lower part there are agricultural areas where strong erosion processes prevail - II erosion category.

The Rogačica River Basin

In the basin of the Rogacica river basin, II and III erosion categories are the most represented, with significant category I participation. Brown skeletal soil on shales and intensive agriculture on sloping terrain are the main causes of erosion processes.

The Rzav River Basin

The lower part of the Rzav River basin is located in Republica Srpska. In the Serbian part of the basin, slight erosion (75%), medium (15%) and heavy erosion (10%) are most prevalent. Most of the Rzav River basin is under forests (about 55% of the basin area) followed by shrubby and herbaceous plant communities, grasslands, arable land, and pastures. Heavy erosion is present in the area of Kršanje Mountain in the Beli Rzav Basin and in the Šargan Mountain area in the Crni Rzav Basin.

The Lim River Basin

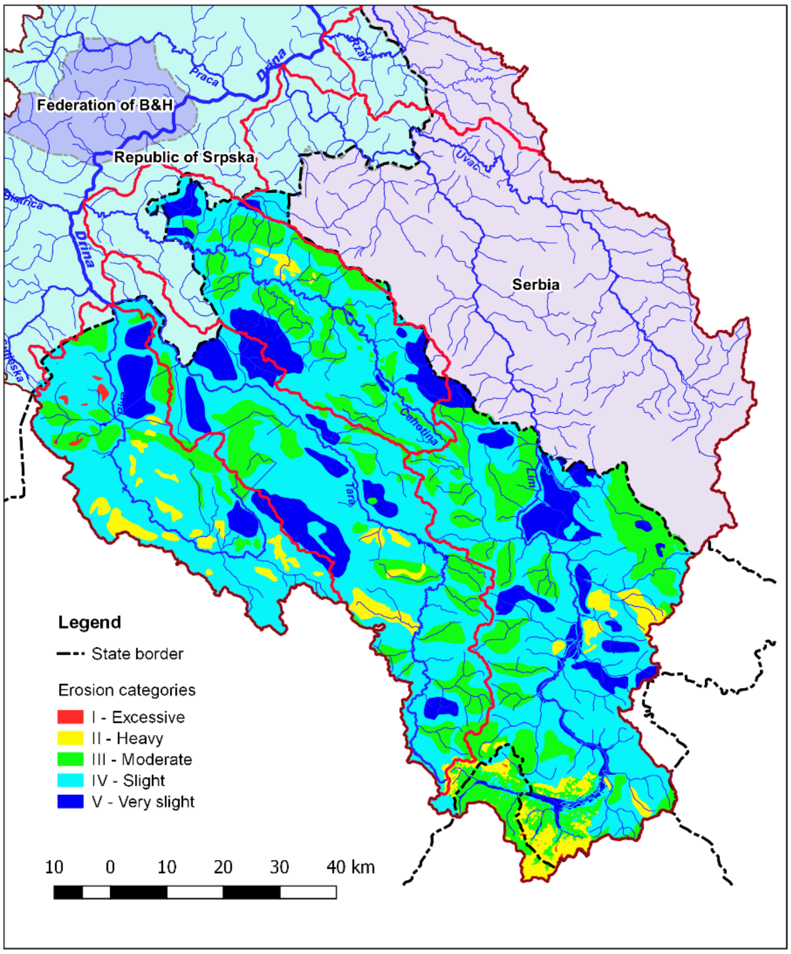
The Lim River springs in Montenegro, passes through Serbia and flows into the Drina River in RS. Although part of the Lim River basin in Serbia according to the erosion map is characterized by V category (65%) and IV category erosion (27%), the amount of erosion material in river beds and reservoirs gives a completely different picture of the state of erosion. A general feature of the watershed in the basin is the large longitudinal fall of the riverbed and the large fall of the catchment areas.

5.3.1 Montenegro

The map is produced using "Erosion Potential Method" (EPM).

The part of DRB in Montenegro is specific in relation to other areas. Namely, for the same erosion category there is a wide range of values of erosion intensity, i.e. specific production of erosion deposits is depending on the position of a particular basin, and there are also large differences within individual sub-basins.

Specific types of erosion, which are characteristic for the karst areas are prevalent, but there are other forms of erosion. The relief is extremely steep and suitable for the occurrence and development of erosion processes.



Map of erosion in the Drina river basin in Montenegro

Erosion categories in the Drina River basin in Montenegro

Category of erosion	I - Excessive	II - Heavy	III - Moderate	IV - Slight	V - Very slight
Participation	0.30%	4.63%	20.93%	59.41%	14.74%

Erosion on major sub-basins of the Drina River in Montenegro

The Lim River Basin

In the Lim River Basin in Montenegro, the largest area is occupied by IV category (56%), then III category (25%), while the areas with II and I category are represented at 6%. However, huge amounts of erosion sediment are transported through the Lima basin, which originates mostly from the steep torrential tributaries of the upper part of the basin. Another significant factor in erosion is the excessive felling of trees.

The Tara River Basin

The Tara is a typical karst river with few tributaries. The most common are IV (59%), V (20%) and III (17%) erosion categories. Low intensity erosion processes are represented in the lower parts of the basin, and in the upper part of the basin of slightly higher intensity.

The Piva River Basin

The Piva River is a typical karst river in which the basin is the least represented by IV and III category with a significant share of II erosion category. High mountains, large longitudinal slopes, the presence of bare rox (4%) and open spaces with little or no vegetation (11%) are the causes of the highly developed erosion processes and the appearance of a large amount of sediment reaching the riverbeds.

The Ćehotina River Basin

The Cehotina River basin covers the territory of Montenegro and RS. In the Ćehotina River basin, weakest erosion (52%) is most prevalent, followed by very slight erosion (26%), moderate (19%), heavy (1%) and excessive erosion (1%). The most pronounced are the processes of fluvial erosion, which are manifested by landslides, destruction of the coasts, erosion and triggering of powerful sediments formed by long-term sediment deposition. Intensive erosion processes have occurred on land that has been improperly used and other natural conditions are unfavourable for the restoration and regeneration of vegetation. Steep slopes, irregular tillage and then climatic and soil conditions influenced both the intensity and the arrangement of erosion processes.

5.3.1Republic of Srpska

The erosion map of the Drina River basin was made using the empirical method S. Gavrilovic, modified from erosion potential method.

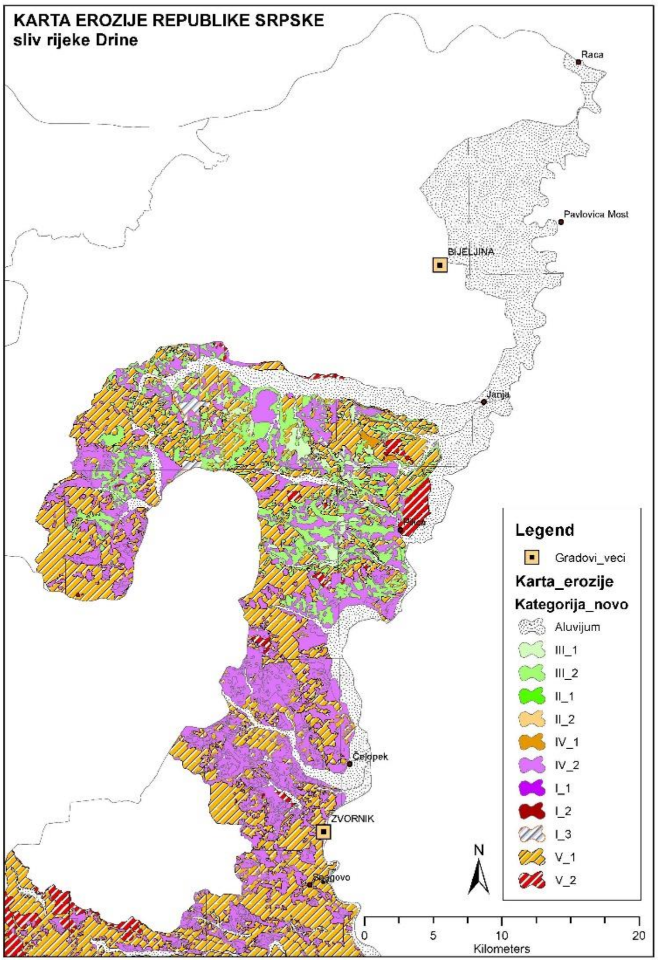
This method are supplemented tables for determining the parameters that are part of the erosion coefficient calculation form (Z).

Erosion intensity mapping is performed directly in the field, visually, with the help of tables of parameters for determining the erosion coefficient (Z) and the corresponding cartographic bases: topographic, geological, pedological, etc.

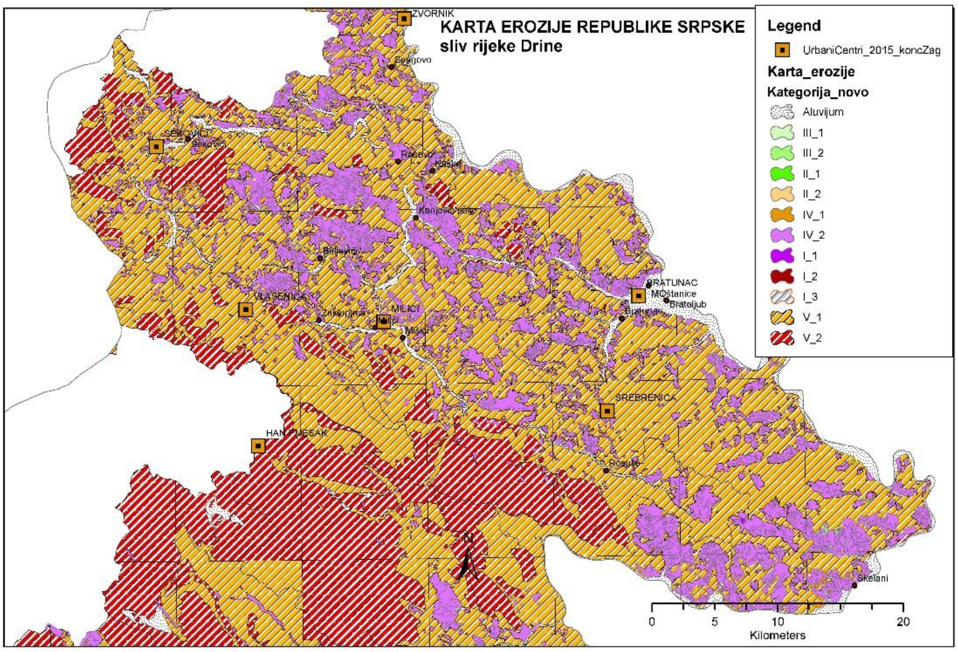
The modified Gavrilovic method differs from the erosion potential method by evaluating one of the parameters for the calculation of the erosion coefficient Z. This parameter observed the erosion process (φ), which in the modified Gavrilović method has values of 1.5, while by the erosion potential method the value of the coefficient (φ) is 1.0. Also, the term "erosion accumulation" was introduced where erosion has a value of 0.

These are the basic differences in the classification of erosion categories, as in the example of the lower Drina River basin (in the Janja River basin), where there is no erosion at all according to the modified Gavrilovic method, while according to the EPM, the lower part of the river basin belongs to the V category.

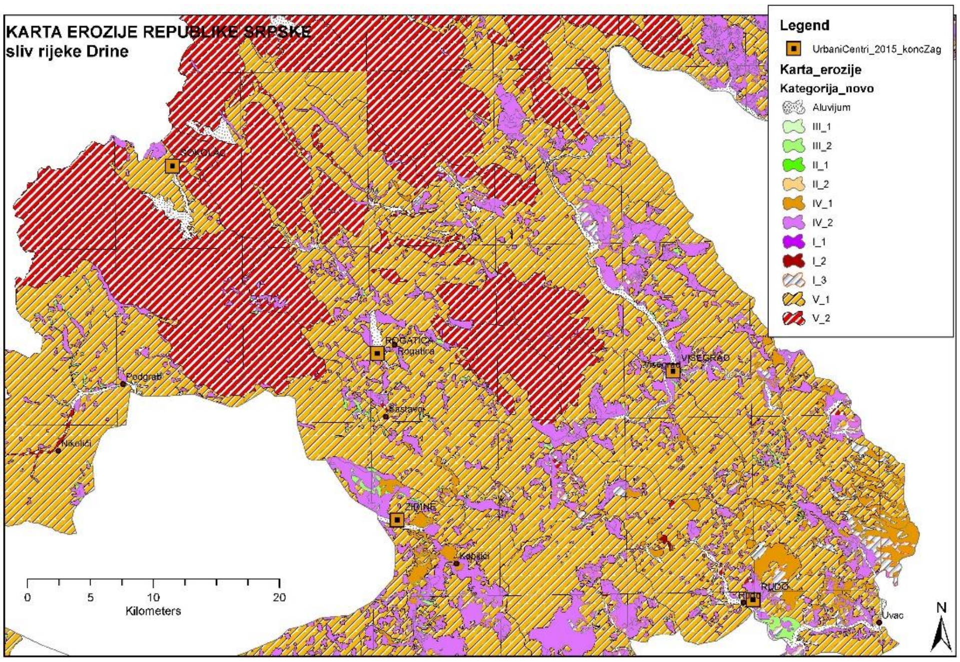
The following figures present data received from Republic of Srpska (4 maps, all in .pdf formats).



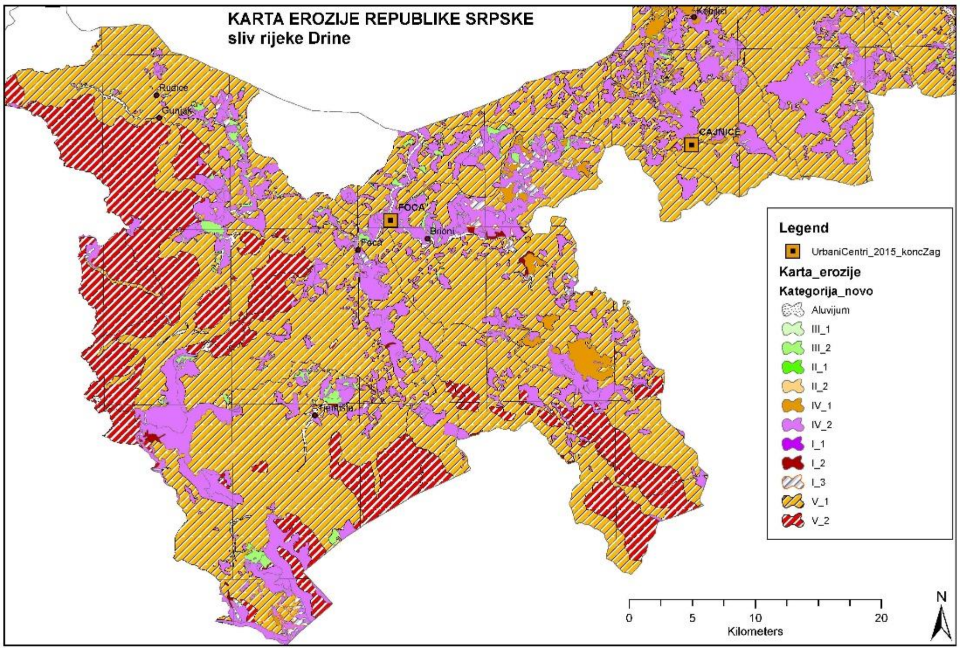
Map of erosion in the Drina river basin in Republic of Srpska (Part 1) (Source: JVP "Vode Srpske")



Map of erosion in the Drina river basin in Republic of Srpska (Part 2) (Source: JVP "Vode Srpske")

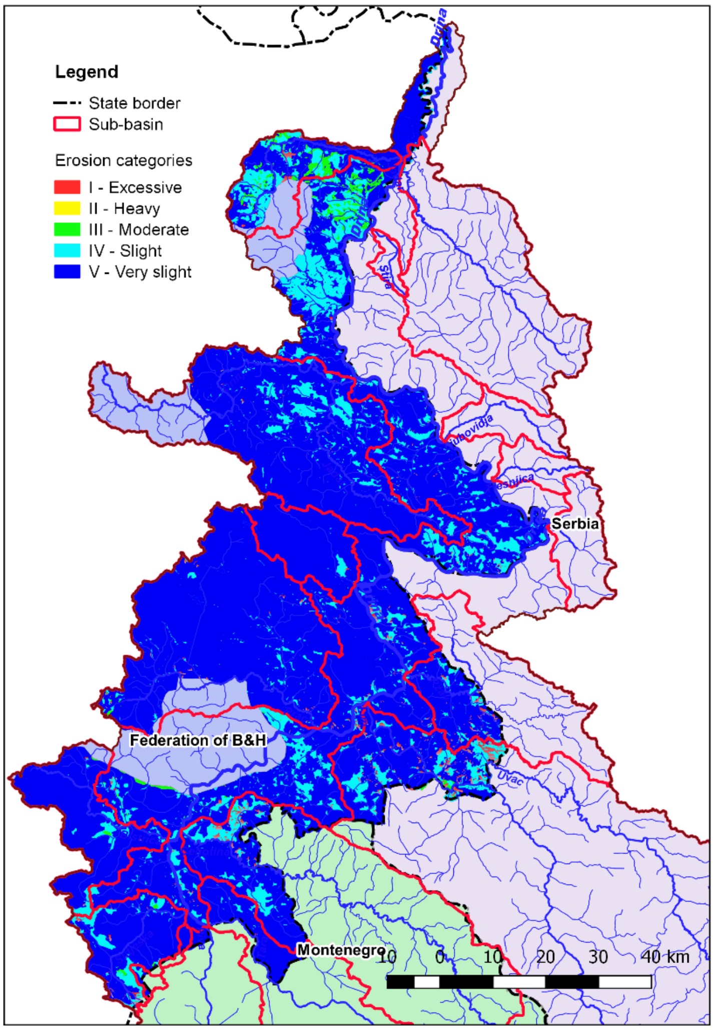


Map of erosion in the Drina river basin in Republic of Srpska (Part 3) (Source: JVP "Vode Srpske")



Map of erosion in the Drina river basin in Republic of Srpska (Part 4) (Source: JVP "Vode Srpske")

To fit these data into the DRB overall maps, 12 erosion subcategories had to be grouped into 5 erosion categories.



Map of erosion in the Drina river basin in Republic of Srpska

Erosion categories in DRB part within Republic of Srpska

Category of erosion	I - Excessive	II - Heavy	III - Moderate	IV - Slight	V - Very slight
Participation	1.08%	0.04%	2.83%	19.02%	77.03%

Forests and IV and V erosion categories are represented in most of the Drina basin in RS. The strongest erosion processes take place in the Janja, Tamna basin, part of the Drinjača river basin, in the Lim, Rzav and Ćehotina basins. Fluvial or river erosion is characteristic of most streams in this area.

Erosion on major sub-basins of the Drina River in Republic of Srpska:

The Janja River Basin

In the Janje River basin, there are mostly slight erosion categories, although the basin is classified as a river basin producing large amounts of erosion deposits. The Mezgrajica basin is most endangered, where excessive erosion is the most prevalent. As a result, huge amounts of sediment are deposited, partly deposited in the valley of the Janja River and partly reaching the stream of the Drina River.

The Sutjeska River Basin

The basin is mostly represented by very slight erosion, slight, moderate and excessive erosion category. Much of the Sutjeska River basin is under forests (about 60% of the basin area) followed by shrubby and herbaceous plant communities, agricultural land, pastures, thinned vegetation and stripped rock.

The Drinjača River *Basin*

The basin is most represented by very slight erosion (78%) and a slight erosion category. The geological base is composed of limestones, dolomites and much less volcanogenic-sedimentary formations. Most of the Drinjača River basin is under forests (about 70% of the basin area) followed by agricultural land, pastures and shrubby and herbaceous plant communities.

The Bistrica River Basin

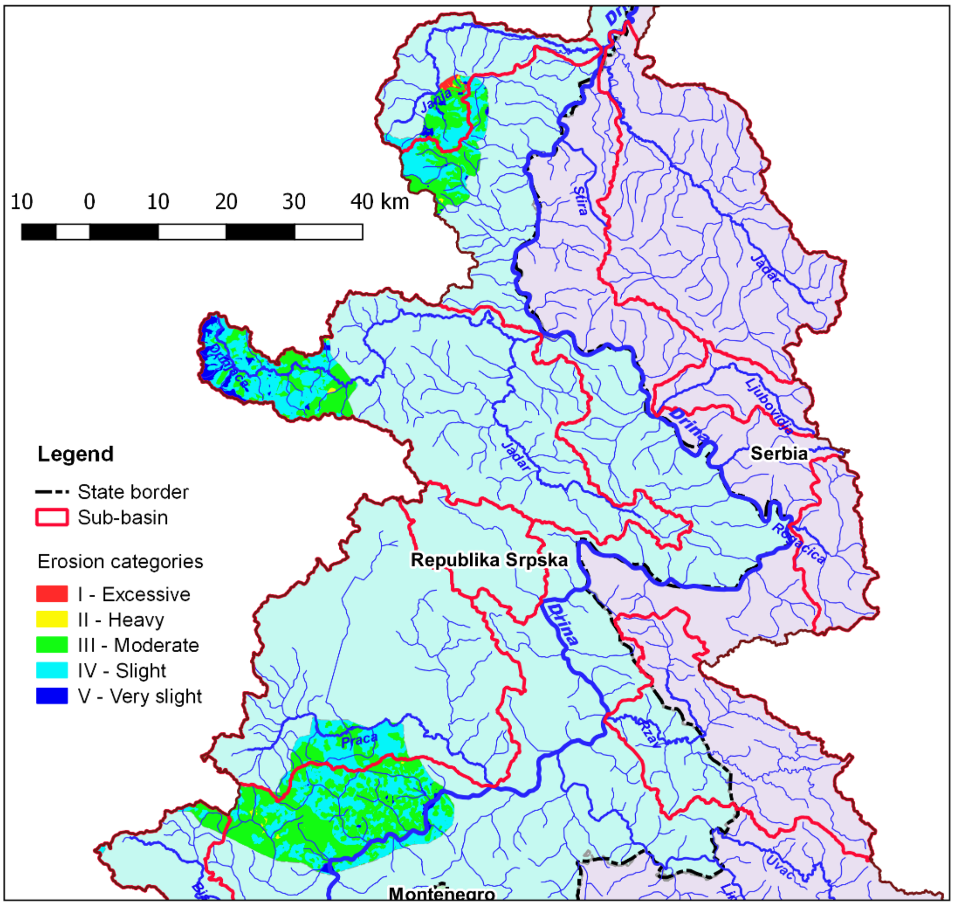
The basin is most represented by very slight erosion (about 80%), slight and moderate erosion category. Most of the Bistrica River basin is under forests (about 65% of the basin area) followed by shrubby and herbaceous plant communities, agricultural land and pastures.

The Prača River Basin

Although very slight erosion (90%), slight and moderate erosion category is most represented in this basin, large quantities of erosion material are produced, especially from the upper part of the basin and sub-basins of Brnjička river and Vinčica. Most of the Prača River basin is under forests (about 60% of the basin area) followed by agricultural land, pastures and shrubby and herbaceous plant communities.

5.3.1Federation of Bosnia and Herzegovina

The erosion map for the part of DRB in the Federation of Bosnia and Herzegovina was prepared within this Study, according to the method of erosion potential (EMP) and based on data available in JCWI (DTM) and from publicly available sources (Corine Land Cover 2018). The result is presented on picture bellow.



Map of erosion in the Drina river basin in Federation of Bosnia and Herzegovina

Erosion categories in DRB part within Federation of Bosnia and Herzegovina

Category of erosion	I - Excessive	II - Heavy	III - Moderate	IV - Slight	V - Very slight
Participation	0.43%	1.09%	46.64%	44.07%	7.78%

The territory of the Federation of BiH in the Drina River Basin is 875 km2, which is approximately 5% of the total basin territory. The territory includes part of the Prača basin, 4 smaller tributaries of the Drina River, the upper part of the Drinjača River basin, part of the upper Janja basin, the upper part of the Sapna basin and the upper parts of the Tavna basin, Lokanjska river and Jasenička river.

Part of the Prača basin and smaller tributaries of the Drina

III and IV erosion categories are the most represented in this part. The most intensive erosion processes take place on agricultural land, which is abundant here.

The upper part of the Drinjača River basin

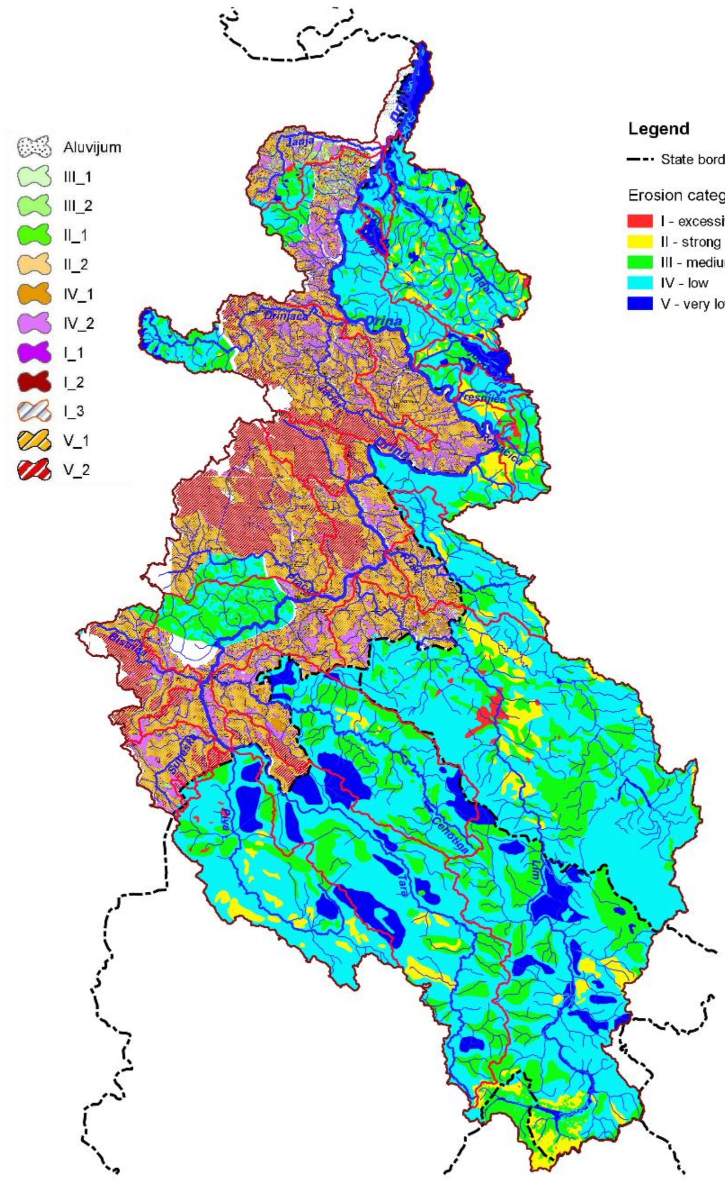
III and IV erosion categories are the most represented in this part. In this part of the basin, forest vegetation is most prevalent, while agricultural areas are second one. The most intense erosion processes take place in the riverbed.

The upper part of the Janja River basin and the parts of the river basins nearby

In this section, the most represented are III and IV erosion categories with a significant share of I and II categories. The most intensive erosion processes take place in the Janja basin on the Jasikovac and Mejdan mountains.

5.4 Compilation of the erosion map for the entire DRB

Within this Study, all available data were compiled and a new erosion map for DRB prepared. It can be seen that there are differences between the right side of the map (Montenego and Serbia), where erosion classification is based on “Erosion potential” method (EPM) and five erosion categories are distinguished (ranging from very low to excessive) and the left side (mainly Republic of Srpska) where erosion classification is based on “modified Gavrilovic method” (mainly very low erosion).



Map of erosion in the Drina river basin

If sub-categories defined in Republic of Srpska are merged into 5 categories (as example: I_1+I_2+I_3=I), the percentages of erosion in DRB are as presented in the next table.

Erosion categories in the Drina River basin

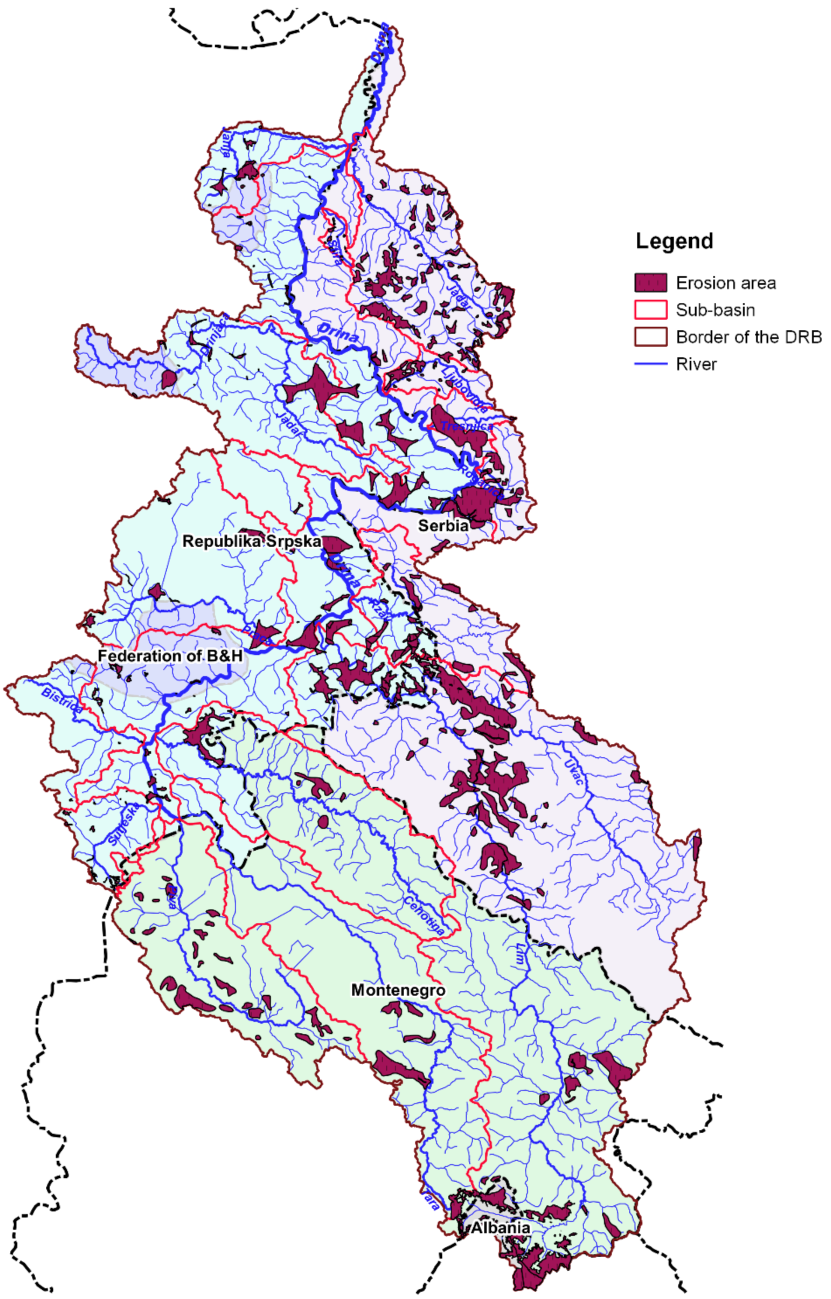
Category of erosion	I - Excessive	II - Heavy	III - Moderate	IV - Slight	V - Very slight
Participation	0.93%	4.27%	15.95%	44.98%	33.87%

5.5 Present areas prone to erosion in DRB

The erosion areas shown on the following map comprise the areas of the most intensive erosion processes (I, II and partly III category).

Erosion areas are widespread in all major sub-basins of the Drina River (Jadar, Rogacica, Lim, Piva, Tara, Sutjeska, Drinjaca, Janja). In most parts, these are steep terrains with erodible geological substrate, as well as the areas that have been adversely affected by excessive logging, fires and other negative effects.

It is necessary to update / determine erosion areas in the DRB, taking into account that new erosion areas may emerge if any of the factors relevant to erosion development change in the future.



Map of erosion areas in the Drina river basin

6. SEDIMENT DEPOSITION AREAS

The largest sediment deposition areas in the Drina River basin are: within reservoirs (most of them used for hydro-power production), on mouths of tributaries and on the mouth to the Sava River.

6.1 Sediment deposition in reservoirs

A number of reservoirs exist in DRB, and most of them are used for hydropower production (only exceptions are Snježnica and Otilovići).

No	Reservoir	River	River basin area [km^2]	Year of construction	Total volume V_u [10^6 m^3]	Active volume V_k [$10^6 m^3$]
1	Uvac	Uvac	920	1979	200	160
2	Kokin Brod	Uvac	1170	1962	250	209
3	Radojnja	Uvac	3500	1959	7.6	4.1
4	Potpeć	Lim	3605	1967	27.5	19.8
5	Otilovići	Ćehotina	352	1981	20.7	13.3
6	Mratinje	Piva	1758	1973	890	790
7	Višegrad	Drina	13310	1988	161	101
8	Bajina Bašta	Drina	15195	1966	340	218
9	Lazići	Beli Rzav	-	1984	170	150
10	Zvornik	Drina	17423	1955	89	23
11	Snježnica	Rastošnica	39	1985	23.1	17.9

Data on sediment deposition in reservoirs is available only for some of them and presented bellow in the downstream-upstream order.

Drina River, Zvornik HPP reservoir

HPP Zvornik operates from 1955. Its initial volume was $95{\cdot}10^6 m^3$ (active volume $28{\cdot}10^6 m^3$, and volume for sediment deposition $67{\cdot}10^6 m^3$). Until 1965 (when the upstream HPP Bajina Bašta was built) the reservoir lost app. 30% of its initial volume. The latest survey was done in 2005 and revealed that its volume is reduced to $41{\cdot}10^6$ m^3 which means that more than 50% is filled with sediment. The sedimentation is clearly visible since large islands and bars are formed.

Visible sedimentation in the Zvornik reservoir

Drina River, Bajina Bašta HPP reservoir

HPP Bajina Bašta started the operation in 1966. It is 50-55 km long and narrow (average width is 400 m), while the water depth at the dam is 80 m. The only tributary in the reservoir range is Rzav. Anti-erosion measures for protection of the reservoir were planned between 1953-1970 but were not implemented.

Some $25 \cdot 10^6$ m^3 of sediment ($2.5 \cdot 10^6$ m^3/year in average) was retained in the first ten years of reservoir operation. After that the rate of sedimentation lessened, since the upstream dams and HPP were buit (HPP Potpeć in 1967, HPP Piva in 1976, HPP Uvac in 1979 and HPP Višegrad in 1989. The last survey was done in 1989, while an estimate from 2002 pointed out that the total volume of the reservoir is $283 \cdot 10^6$ m^3 (17.2 % less than initial). This leads to conclusion that sedimentation in the reservoir of HPP Bajina Bašta is not very serious.

Drina River, Višegrad HPP reservoir

HPP Višegrad was built in 1989, as the most upstream reservoir on the Drina main course, at the end of HPP Bajina Bašta backwater. The initial reservoir volume was diminished for only $6.73 \cdot 10^6 m^3$ between 1991 and 2005 or 0.5 $10^6 m^3$/year, by retaining of the sediment incoming from the upstream Drina reach and also erosion of riverbanks. Since Višegrad dam is equipped with powerful bottom outlets which enable sediment flushing/sluicing during floods, this reservoir is not prone to severe sedimentation.

Piva River, Piva (Mratinje) reservoir

The Piva HPP on the Piva River has the largest reservoir in DRB, built in 1973. Initial asumption, that the sediment inflow from a rather small upstream catchment will not endanger the reservoir, was confirmed by 2011 survey. The reservoir survey has shown that after 39 years the reservoir volume was dimished for 75 $10^6 m^3$ i.e. some 8 % .

Lim River, Potpeć reservoir

Sediment related problems the Potpeć reservoir (as clogging of water intakes) started in 1967, when the dam and HPP were built. After that the reservoir surveys were more frequent, and the attempts of sediment flushing/sluicing were done. The results of sediment sluicing done in 1979 and 1980 were negative, as there was a large amount of mud being withdrawn thus destroying the river ecosystem downstream of the dam. Till 2002, the total volume of this reservoir was reduced for $18.5 \cdot 10^6$ m^3.

Uvac river, Kokin Brod i Uvac reservoirs

The Kokin Brod and Uvac reservoirs have very large volumes (relative to the basin area of about 1000 km^2). Given the relatively low sediment input, it was estimated a priori that these reservoirs would not be endangered by sediment and the issue of sedimentation was not given sufficient attention. This assumption was proved by surveys which showed that only 3% of reservoir volume is filled with sediment (Kokin Brod retained $7.9 \cdot 10^6$ m^3, and Uvac $6\text{-}7.9 \cdot 10^6$ m^3).

6.2 Sediment deposition on the river mouths

Sediment deposition is present on the mouths of all tributaries, on free-flowing and impounded sections of the Drina and other rivers. Data on the volumes of sediment accumulated are not known.

Example of a sediment bar at the mouth on free flowing section: the mouth of Ljubovidja River (right tributary of Drina)
(Source: JCWI)

Example of a sediment bar at the mouth on impounded section: the mouth of Boscanska River (right tributary of Drina in Zvornik reservoir)
(Source: JCWI)

Sediment deposition on the mouth of the Drina to Sava River is a well-known problem, that influences the water and sediment regime of both rivers. The investigation of possible river engineering activities which might solve the problem are in the initial phase.

Huge gravel bars at the mouth to Sava River
(Source: http://www.savacommission.org)

7. IDENTIFICATION OF MEASURES

7.1 Set of possible measures

Land erosion and torrents create enormous and long-term damages, threatening multiple sectors at the same time: agriculture, forestry, water management, traffic, communications, communal infrastructure, settlements, etc.

Anti-erosion measures are actions that affect the cultivation, maintenance and management of land, forests and water, and the ways in which they are exploited. These include various legal regulations and administrative, economic, educational and propaganda measures, as well as other measures that have a socio-economic character.

The following groups of works and measures can be distinguished:

Technical works - construction of longitudinal and transverse structures in torrential riverbeds for flood protection and containment of torrential deposits. This group of works also includes the construction of micro retentions and small reservoirs;

Biological and biotechnical works - afforestation, construction of contour trenches, terraces, wickerwork, live belts for wind and snow protection, mud filters, reclamation of bushes, reforestation of neglected forests and bushes, etc;

Agro-technical works - reclamation of agricultural land, repair of soil structure, introduction of crop rotation, terracing, contour-belt tillage, irrigation, application of anti-erosion agro-technology, application of the "sustainable agriculture", etc;

Economic and management measures – measures related to land use, exploitation of forests, pastures, etc.;

Administrative measures – enactment and enforcing of decisions and regulations with regard to the mandatory introduction of contour tillage, prohibition of overgrazing on pastures and forest land, prohibitions of deciduous trees, proclamation of protective forests and pastures, reorientation from cultivation of annual crops to perennial agricultural crops, introduction of perennial crops rotation, planned utilization of agricultural land, planned management of forests and similar restrictions within eroded areas or torrential catchments. The first step is designation of erosion areas;

Educational and propaganda measures - courses, lectures, documentaries, exhibitions, printing of popular books and brochures.

7.2 Strategic goals and measures set in DRB countries

All DRB countries envisaged a set of measures related to erosion and deposition of sediments in their strategic documents.

7.2.1Montenegro

An important prerequisite for ensuring the efficiency of flood protection systems and the regulation of water flows is the erosion and torrential protection works in the upper parts of the catchments. An integrated approach to the regulation of torrents and erosion protection in the territory of Montenegro implies the coordination and synchronization of all activities and measures in this domain, while respecting the needs and interests of individual stakeholders. When it comes to protection against torrents, access to this problem depends on the size of the watercourse. In the case of larger torrential flows, protection against the adverse effects of water is achieved by classic measures of watercourse regulation and flood protection. In the case of smaller torrential flows, measures for the regulation of these watercourses are treated as part of the complex anti-erosion management of the basin. Erosion is a natural phenomenon, but also a process whose intensity is most affected by human activity, and it is the only area that can be brought under control and by changing the way land is used to reduce the intensity of erosion to an acceptable extent. Within this framework, provision should also be made for the change of use of particular surfaces. Wherever possible, the protection of watercourses against erosion should be addressed by protective vegetation. Existing forest areas in catchments should be maintained and expanded, especially in mountainous and mountainous areas with high erosion risks. Planned conversion of low-productive and degraded pasture land into forest complexes, as well as land reclamation of degraded forest land, can produce significant anti-erosion effects. Population education can also contribute significantly to preventative protection, as erosion can be substantially reduced by proper land use and the conservation of vegetation cover.

The Water management strategy for the territory of the Montenegro proclaimed the following goals:

<u>**Operational goal 1:**</u> **Establish the legal framework for improving the protection against erosion and torrents.** Measures for achieving the goal:

- Adopt a bylaw on the criteria for determining erosion-prone areas;
- Develop a new erosion map of Montenegro in the initial ten-year period, prepare necessary studies and determine erosion-prone areas (obligation of the competent bodies of local self-government), along with specific conditions for their use and necessary works and measures, while complying with environmental requirements; the studies must be in accordance with the water management plan for the particular river basin district and must constitute the basis for drafting an Emergency Protection and Rescue Plan - the part relating to the protection from erosion and torrents;
- Ensure the integration of erosion protection issues in urban planning and forestry and agricultural plans.

Operational goal 2: Improve the conditions of protection against erosion and torrents. Measures for achieving the goal:

- Implement preventive, technical and biological protective works and measures in accordance with studies completed on determining erosion-prone areas;
- Create and continuously update the cadastral registers of erosion processes and torrential flows and implemented measures, and enter updated data into the water information system;
- Increase the efficiency of inspection service and other competent authorities dealing with the state of erosion-prone areas and torrential flows;
- Educate the population on the consequences of improper behavior in erosion-prone and torrential flow areas.

Operational goal 3: Monitor the situation and maintain structures and works. Measures for achieving the goal:

- Ensure continuous monitoring of erosion processes and condition of torrential beds and structures for protection against erosion and torrents;
- Regularly maintain the built structures and executed biotechnological and biological protection works according to the annual programme and in accordance with relevant standards and norms;
- Repair structures and executed biotechnological and biological protection works damaged by natural and anthropogenic influences, in a manner that does not disturb the natural balance of the watercourse/torrential flow and its catchment area.

Measures which are indicated for specific areas within DRB include:

1. **Reduction of sediment from soil erosion and surface runoff in the area of the Tara River source (Komovi massif)**

   Key aspects / pressure: Flushing of sediments from the surrounding mountainous areas

   Description of the measure: Development of a forestry study and action plan in this region with attention to sustainable forestry and afforestation activities to reduce soil erosion from the surrounding mountain slopes.

   Other notes: Reduction of sediment leaching from afforested areas in the surrounding mountainous area (Forestry)

2. **Sediment reduction from soil erosion, surface runoff and prevention of sediment deposition in Plav Lake**

   Key aspects / pressure: Due to natural erosion processes and anthropogenic factors, sediment and organic matter are rapidly deposited in Plav Lake

   Description of the measure: Due to natural erosion processes and anthropogenic factors, sand and gravel are rapidly deposited in Plav Lake and biomass accumulation occurs in the shallow parts of the lake. It is necessary to protect the lake from further sanding and

gravel, to reduce external and internal nutrient intake as needed, and to rehabilitate parts of the lake where sand and gravel are deposited

Other notes: This measure is very complex and depends on other measures (eg wastewater treatment, water regulation, etc.).

3. **Reduction of sediment from soil erosion and surface runoff in the municipalities of Plav and Andrijevica**

   Key aspects / pressure: Flushing of sediments from the surrounding mountainous areas

   Description of the measure: Development of a forestry study and action plan in this region with attention to sustainable forestry and afforestation activities to reduce soil erosion from the surrounding mountain slopes.

   Other notes: Reduction of sediment leaching from afforested areas in the surrounding mountainous area (Forestry)

4. **Reduction of sediment from soil erosion and surface runoff in the municipalities of Berane and Bijelo Polje**

   Key aspects / pressure: Flushing of sediments from the surrounding mountainous areas

   Description of the measure: Development of a forestry study and action plan in this region with attention to sustainable forestry and afforestation activities to reduce soil erosion from the surrounding mountain slopes.

   Other notes: Reduction of sediment leaching from afforested areas in the surrounding mountainous area (Forestry)

7.2.1Serbia

Water management strategy for the territory of the Republic of Serbia set 3 main goals to be achieved till 2034 and a number of measures which are planned for the overall country area.

Operational goal 1: **Establish the legal framework for improving the protection against erosion and torrents.** Measures for achieving the goal:

- Adopt a bylaw on the criteria for determining erosion-prone areas;
- Develop a new erosion map of the Republic of Serbia in the initial ten-year period, prepare necessary studies and determine erosion-prone areas (obligation of the competent bodies of local self-government), along with specific conditions for their use and necessary works and measures, while complying with environmental requirements; the studies must be in accordance with the water management plan for the particular river basin district and must constitute the basis for drafting an Emergency Protection and Rescue Plan - the part relating to the protection from erosion and torrents;
- Ensure the integration of erosion protection issues in urban planning and forestry and agricultural plans.

Operational goal 2: Improve the conditions of protection against erosion and torrents. Measures for achieving the goal:

- Implement preventive, technical and biological protective works and measures in accordance with studies completed on determining erosion-prone areas;
- Create and continuously update the cadastral registers of erosion processes and torrential flows and implemented measures, and enter updated data into the water information system;
- Increase the efficiency of inspection service and other competent authorities dealing with the state of erosion-prone areas and torrential flows;
- Educate the population on the consequences of improper behaviour in erosion-prone and torrential flow areas.

Operational goal 3: Monitor the situation and maintain structures and works. Measures for achieving the goal:

- Ensure continuous monitoring of erosion processes and condition of torrential beds and structures for protection against erosion and torrents;
- Regularly maintain the built structures and executed biotechnological and biological protection works according to the annual programme and in accordance with relevant standards and norms;
- Repair structures and executed biotechnological and biological protection works damaged by natural and anthropogenic influences, in a manner that does not disturb the natural balance of the watercourse/torrential flow and its catchment area.

It is estimated that at least EUR 280/ha should be invested in regulating land with low erosion rates, where no additional afforestation is needed, while in the cases of high erosion rates specific costs reach EUR 2,000 /ha.

7.2.1 Republic of Srpska

When considering the criteria for selecting the priority of erosion and torrential protection works, the following should be taken into account:

- the importance of facilities for water management in Republika Srpska,
- the degree of vulnerability of the structures from deposition,
- the degree of sensitivity of the function of the objects to deposition,
- age of buildings (for existing buildings),
- planned construction time of the facilities (for future facilities).

The valorisation of priorities can be summarized as follows:

Due to the water management importance and the degree of susceptibility to deposition, the absolute priority is given to reservoirs. In second place are water intakes for water supply and for

larger reclamation systems. The riverbeds are regulated in third place, especially in populated areas.

The choice of priorities for the protection of individual reservoirs depends on the role of the reservoir in the water management system of the Republika Srpska, as well as on the degree of vulnerability to backfilling. Important for the water management of Republika Srpska is the existing (or under construction) large reservoirs for water supply.

As far as the risk of reservoirs from backfilling is concerned, it depends, on the one hand, on the natural conditions in the basin, and on the other, on the water management characteristics of the reservoirs (purpose of the reservoir, importance in the water management system of Republika Srpska, the size of the basin and the degree of water levelling, etc.).). A significant priority is the protection of settlements, industrial and energy facilities and roads from torrential floods.

The tasks that must be accomplished in the coming period are:

- Upgrading the legal framework and more fully regulating erosion in the Republika Srpska
- Preparation of documentation on the state of erosion and lushness of streams with regular records of all changes. (Erosion Map, Cadastre of torrents)
- Development of General, Preliminary and Main Designs for anti-erosion works.
- List of constructed facilities for anti-erosion control of torrential watersheds. (Cadastre of performed anti-erosion works).
- Repair of damaged structures and completion of biological and biotechnical works is one of the first activities in the construction of the anti-seizure protection system.
- The construction of new facilities, technical, biotechnical and biological, is a step that must accompany the repair of damaged and demolished facilities.

7.2.1 Federation Bosnia and Herzegovina

It is necessary to develop and adopt an Erosion Protection Strategy and Program under the coordination of the competent Ministry of Agriculture, Water Management and Forestry of the FBiH, the Ministry of Environment and Tourism, as well as the Ministry of Spatial Planning.

Measures:

- Development of the Erosion Protection Program. Development of the Erosion Protection Program.
- Implementation of general anti-erosion measures.

Regardless of local conditions, general anti-erosion measures are: legislative measures, development of erosion cadastre, monitoring of erosion processes, education of the population, integration of erosion protection issues into: spatial plans, into forest bases and, of course, planning documentation of the water sector. Erosion can be significantly reduced by proper tillage and conservation of plant cover.

Erosion damage repair

The approach to remedial measures must be analysed in detail, with emphasized priorities, in order not to disturb the natural balance of the watercourse and the catchment area. Erosion protection should be carried out according to the established criteria, which depend on: the importance and priority of the protective water body, the degree of threat of the backfill, the degree of sensitivity of the backfill, the degree of justification of the works (rates of profitability).

7.3 Proposal of key measures in DRB

Develop and update erosion maps to guide actions

- Prepare new erosion maps and define areas prone to erosion every 10 years, using the common methodology in all DRB countries
- Integrate erosion measures into spatial plans and forestry and agricultural master plans
- Integrate erosion and sedimentation map into the Sava GIS

Apply and monitor appropriate erosion control measures

- Apply measures to reduce erosion and torrent impact
- Prepare and maintain cadastre of erosion areas and structures built for anti-erosion and torrent control purpose
- Regularly assess the conditions of the existing structures and maintain them properly
- Apply biological and biotechnical measures to reduce soil erosion, providing beneficial results in synergy with torrential flood control and sustainable forestry

Raise awareness, promote and exchange good practice

- Raise awareness of sectoral actors and the population on the consequences of inadequate land use practice and appropriate recommended anti-erosion measures
- Exchange experience about good practices among DRB countries

Establish sediment monitoring system in DRB

- Set a network of suspended and bed load monitoring stations
- In cooperation with HPP operators regularly survey the existing reservoirs and analyse the sedimentation process development
- Investigate sediment quality, especially of sediments retained in reservoirs
- Regularly survey cross sections along the Drina River and the main tributaries.